MODEL SOLAR BOAT

MASTER WORKSHOP

DOCUMENT

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This document is the composite of a number of documents which were produced for workshops conducted for various schools together with results from testing of boat components.
It is intended to give a basic understanding of the critical features involved in building a boat that functions. Remember it is aimed at supervisors not students. It is hoped that it will enable the supervisors to better guide their students towards a boat that works.
The suggestions for possible testing were added at the request of Teachers you can choose to use or ignore them.
The publication **Model Solar Boat Guide by Wayne Young** available free from our web site is specifically written for students, I would strongly recommend you down load this document.

CAUTION: Test results in this document were obtained using standard production Solar panels, motors and propellers available at the time of testing. Some may no longer be in available. When new components become available their test results will be included in the next edition. Typically the power output of solar cells is increasing constantly as production processes improve. Consequently any new solar panels even if apparently identical to older ones will probably perform better than the test results here indicate.
The combination of components tested was somewhat random and not intended to be the combination to give best results. Neither was it intended to suggest which components are the best or which you should use. The only purpose of this whole exercise was to show how easily a boat that would actually function is to build.

ADDITIONAL RESOURCES:

Model Solar Boat Guide By Wayne Young
Victorian Model Solar Vehicle Committee web site
www.modelsolar-vic.net
Regulations available from web site.

INDEX

COMMENTS ON REGULATIONS

The boat regulations unlike the car regulations are not subject to regular changes. This year however there have been significant changes.

In the junior division the motor specification has been varied significantly it now specifies only "hobby " motors of recommended retail price less than $ 5.00 are permitted. Second hand and reclaimed motors are not permitted in this division.

This change was introduced when limited quantities of high efficiency motors became available at very low cost (< $15.00) if only some competitors could access these motors it would significantly advantage them over others who could not access these motors. This regulation ensures a fair competition for all.

In the Advanced division gearboxes are specifically mentioned as allowed. The use of a speed reduction between the motor and propeller can significantly improve both motor and propeller efficiency with a resultant increase in thrust and boat performance.
Gearboxes are not permitted in the Junior division as this division is for primary students and the additional complexity is considered beyond the normal ability of students at this level.

The basic section of the regulations covering boat requirements lifted from the National regulations is included below. DO obtain and read the complete regulations before commencing your build.

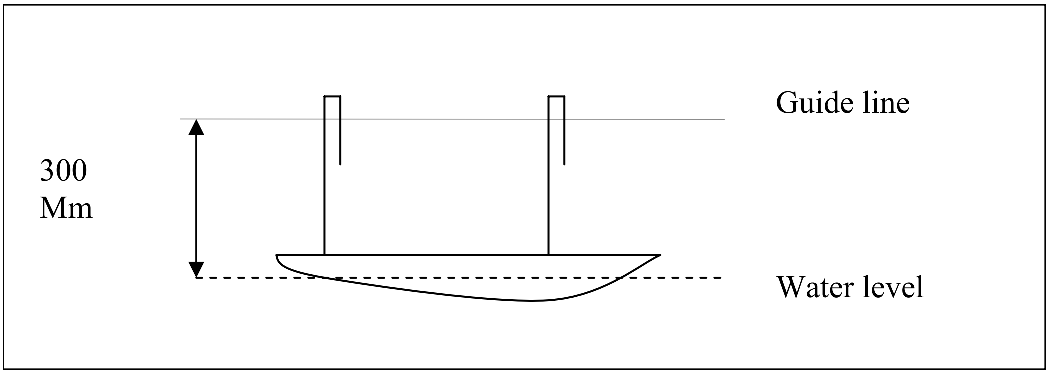
5 BOAT SPECIFICATIONS COMMON TO BOTH DIVISIONS.

To be eligible to compete boats must conform to all specifications, the following list details the specifications which are common to both the Junior and Advanced division. The additional specifications which apply to one division only are detailed in 5.1 and 5.2.

1. The maximum boat length including any front and rear projections, shall be 550 mm to ensure that the boat fits behind the starting line. (see Fig.1)

2. The boat width (including the cells) must be no greater than 300mm at the widest point.

3. To enable boats to steer a straight line, they should be fitted with rods with open loops through which the guide line will run. This line will be located as near as possible to 300mm + or – 25 mm above the water. Other designs than the one shown may be used.



4. Both divisions' boats may be powered only by commercial silicon cells with a maximum active area of 350 square cm. Panels must be securely attached, so that they cannot fall into the water.

5. A functioning on/off switch must be installed between the solar panel and the motor.

6. No commercially available boat hulls or kits may be used. Entrants are to design and construct their own boats in the year of the race. Hulls unaltered from previous state or national competitions are not eligible. Boats re-entered with very substantial modifications must have alterations documented to the satisfaction of the race coordinator.

7. Multiple boats entered by one school/group cannot be of an identical hull design – eg each entry from a school would not be allowed to use a hull vacuum formed using the same mould or made of fiberglass from one mould. Advanced students using vacuum formed or other moulded hulls must have designed and substantially made them themselves.

8. No batteries or energy storage devices are allowed. However capacitors are allowed as part of an electronics system in the advanced division.

9. Each boat must have the school and boat name clearly visible to the starter and judges. Teams will be provided with a "flag" with the boat's number and name this flag is to be affixed to the rear guide wire.

10. Propulsion: there is no restriction on the use of underwater propellers, air propellers, paddle wheels, oars etc.

11. It is strongly recommended that the boat should have a bow section with a minimum radius of 25 mm. This is to ensure they do not become lodged in the 10 mm square mesh of the starting gate.

5.1 BOAT SPECIFICATIONS SPECIFIC TO A DIVISION

As well as conforming to the boat specifications common to both divisions detailed in 5.0, all competing boats must additionally conform to the specifications applicable to their division as detailed below in 5.1.1 for the Junior Division and 8.1.2 for the Advanced Division.

5.1.1 Junior Division

1. Only one hobby motor with a maximum recommended retail price of $ 5.00 is Permitted. Second hand and reclaimed motors from scrapped equipment such As VCR's are not allowed as we cannot verify their performance. Boats using these motors will be required to compete in the advanced division.

2. Only hulls made from drink bottles or cans, polystyrene foam, cardboard or balsa wood (appropriately waterproofed) may be used. Moulded hulls, eg. vacuum formed plastic and fiberglass hulls are not allowed in this division.

3. Maximum cost of the whole boat must be less than $50.00 not counting the solar panels.

4. Boats built by primary students which do not meet these restrictions will be required to compete in the advanced division.

5.1.2 Advanced Division

1. Any type or number of motors may be used.

2. Gearboxes of any type may be used.

3. Any materials including vacuum formed plastic, fiberglass or carbon fiber hulls can be used.

4. Electronics and capacitors may be used, but capacitors over 15,000 uF will be discharged at the start line.

RECENT TRENDS IN BOAT DESIGN

Listed here are the new innovations observed at both the Victorian and National events.

- Use of gearbox with speed reduction between motor and propeller.
- Use of surface piercing propeller.

NEW OR IMPROVED COMPONENTS AVAILABLE

Listed here are any new, upgraded or not in common use components or equipment that have come to notice. Use caution just because it is new does not mean it is better, test and then use your own judgement before rushing in.

- Automax electronics. This unit has been tested and found to function well on the latest Scorpio boat panel when wired in series to give 7 volts. This is the most efficient unit currently available and automatically tracks the panel's maximum power point. Use of such a unit ensures that the maximum power possible is always transferred to the motor and eliminates the need to change panel wiring from series to parallel. CAUTION: Water and electronics do not mix well. A small quantity of water in the wrong place on the board can stop

the unit functioning or even permanently damage it. The unit will function on a solar panel with maximum power point voltage of 6.0 volts.

- Solar panels. Scorpio technology has slightly increased the voltage of their boat panel to better match it to available motors and electronics.
- Gearboxes: Are available from a number of sources including committee members see various State web sites, R & I Instrument Gear Co. Who have adapter components to convert their car drive system into a “stand alone” boat reduction drive system. General purpose gearboxes are available from most hobby shops.
- Motors: Many previously available motors are no longer available. This is true for the motors from Dick Smith which used to feature prominently in this document. In searching for replacement motors testing showed motors now available from CAM Art Craft & Technology have excellent performance characteristics for Junior boats significantly outperforming the previously listed motors.

MODEL SOLAR BOAT
SYNOPSIS OF DESIGN CONSIDERATIONS

- Hull should be stable, have good hydrodynamic shape to minimise drag and have sufficient buoyancy to support solar panel & motor.
- Build the boat as lightweight as possible and keep weight as low down as possible to aid stability.
- Do NOT shade any part of your solar panel. If only one cell in a string of cells connected in series is shaded , the power output from that string of cells will be reduced to near zero.
- Solar cells will produce their maximum power when directly facing the Sun that is when the Sunlight strikes them at 90 Degrees. There will be a power increase just by pointing the cells directly at the Sun compared to when they are laying flat .
  Caution: if you tilt a large single panel up at an angle it will act like a sail, any gains in power output may be lost due to increased air drag as the boat moves. In a strong wind the boat may even be blown backwards.
- Test your boat to determine which solar panel configuration and propeller choice is best in different light conditions. By solar panel configuration we mean do you run with all the cells in series or perhaps two groups of half your cells in series and these two groups parallelled. Or any other configuration. Refer to sections on SOLAR CELLS and PROPELLERS for details. Overloading the motor with too large a propeller or one with too much pitch for the power available from your panel will significantly reduce performance.

- Make certain the propeller shaft and motor shaft are in alignment and remain so at all times, misalignment will waste a lot of power and significantly degrade boat performance. Pay attention to your coupling as power can be lost here. A **SOFT** plastic tube is in common use and is superior to hard couplings.
- Ensure your boats guides are free running on the guide wire and will not disengage with wave action.
- Keep the propeller shaft angle as low as possible to maximise the forward thrust component and minimise the lifting effect, think of a propeller facing directly down it will not push the boat along but just push it upwards.
  Do not have the propeller too close to the water surface or it may suck air down (ventilation) which significantly reduces the thrust. A plate parallel to the water surface above the propeller and below the water surface will help in reducing or eliminating ventilation. Obviously running the propeller deeper in the water will also help but the shaft angle may become an issue.

BOAT SECTIONS IN DETAIL

HULL:

- Must float, remember it has to carry motor and solar cells.
- Be constructed from water resistant materials or if not the material used must be sealed.
- Be stable not roll over, remember wind effects.
- Shape, should have a low drag shape and slip easily through the water.

POSSIBLE TESTING:

Test bouyancy of hull.
Test roll over stability.
Tow hull in tank and record the force required , compare various different hull shapes and choose the best for your boat.

GUIDING:

Normally a wire with a hook bent in the top that hooks over the fishing line guide is used.
CAUTION: Make your guide hook long enough so your boat will not "HANG" on the line or disengage from the line due to wave or wind action.

STARTING:

Either the boat is nosed up to a gate which is rotated down below the water surface or the boat is hand released.

PROPULSION:

Can be any method you like except using the guide wire. Some possibilities are.

- Rowing

- Paddle wheels
- Airscrew
- Conventional water propeller is by far the most common, in fact almost universally used. **Aim to** select **a propeller that transfers all the solar panel power available to the water to drive your boat . Keep the shaft angle low to maximise the forward thrust component and minimise the vertical thrust component.** (See data below for details}
  Use a good quality shaft and stern tube to minimise friction losses. Lubrication of the shaft in the support bearings will also help reduce friction losses.
  In order to understand how a propeller functions in driving a boat we can take the simplified view of a screw advancing in a nut as it is turned and see the propeller doing this in the water. (There will always be some slip that is the propeller will not advance the full distance of its pitch it will advance a distance that is less than this) The distance the propeller would advance in one revolution with no slip is the pitch, increasing the pitch increases the load on the motor. Conversely decreasing the pitch decreases the load on the motor
  An alternative way to envisage how a propeller functions is to look at momentum, the propeller pushes a column of water rearwards at high velocity the reaction force pushes the boat forwards.
  Be cautious a very small propeller can easily use all the power available from your panel , it is common for boats to be fitted with large propellers that overload the motor and pull the solar panel down into a low power operating point .
  SIGNIFICANTLY DEGRADING PERFORMANCE
  See the test results section for propeller details and thrust produced.

PROPELLER TESTING CAUTION:

To obtain accurate propeller test results testing must be conducted on a free running boat.
The very act of holding the boat stationary during testing increases the load on the motor thus introducing errors which can be significant.
As evidence for this the data below is from an actual full size boat.
The full size 6 meters long boat is powered by a 140 HP motor and capable of 8o KPH.
With the boat held stationary in the water and the motor at full throttle it can only manage 3000 RPM. However with the boat running free the full throttle RPM increases to 4500.

POSSIBLE TESTING:

Different sized propellers at different Sun levels, measure thrust obtained or time taken to run the length of a pool. (A different size propeller need not be a propeller of different diameter it could be propeller of the same diameter but different pitch.
Repeat these tests with your solar panel configured differently (eg. series and parallel)

HINT:

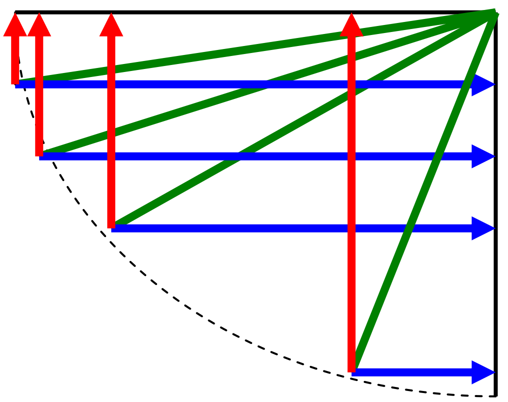
With the boat running free in a pool measure the voltage output from the

solar panel. A voltage output from your solar panel lower than 0.45 volts per cell in series would indicate an overload condition. When overloaded the power available from your solar panel is reduced below the power it could potentially provide.
A voltage higher than this 0.55 volts per cell in series would indicate an underloaded condition where all the power potentially available from the solar panel is not being used. Refer to SOLAR CELLS section later in this document for details.

PROPELLER FORWARD THRUST VARIATION WITH SHAFT ANGLE:

The diagram below represents the forward thrust in BLUE and the Vertical thrust in RED at various shaft angles.
This diagram is to scale so the relative magnitude of the forces is depicted by the line length. The GREEN line represents the propeller shaft angle and magnitude of the propeller thrust. Thrust direction is towards the intersection point. Arrows have not been included to show its direction as the drawing is too cluttered in the corner.

Note how at relatively low shaft angles (near parallel to the water surface) the forward component of the thrust (BLUE) only reduces slightly as angle is increased.
However as the shaft angle exceeds 20 degrees, reduction of the forward thrust component becomes significant.
More importantly the vertical component of the thrust (RED) increases rapidly as the shaft angle is increased. This can have a significant effect on boat performance as it lifts the stern and changes the balance of the boat , consequently influencing the way the boat moves through the water.



GREEN LINE REPRESENTS MAGNITUDE AND DIRECTION OF PROPELLER THRUST
BLUE LINE REPRESRNTS MAGNITUDE AND DIRECTION OF FORWARD COMPONENT OF PROPELLER THRUST (DRIVE PORTION)
RED LINE REPRESENTS MAGNITUDE AND DIRECTION OF VERTICAL COMPONENT OF PROPELLER THRUST (NON DRIVE THRUST)

Diagram 1. Thrust Variation with Shaft Angle

SOLAR CELLS:

There are many solar cells available that can be used for model boats and will satisfy the area requirements of the regulations.

How do they work? Simplistically light falling on the solar panel imparts its energy to electrons in the outer orbit of the atoms in the silicon crystals of the solar panel.

This gives the electrons sufficient energy to break free and become an electric current capable of doing work.

SOME SOLAR CELL BASICS:

- Connecting cells in series adds the voltages of the cells. Silicon cells produce about 0.5 Volts per cell so 3 cells in series will give about 1.5 Volts. (Series is when the + terminal of one cell is connected to the – terminal of the next cell)
- Connecting cells in parallel adds the current. If each cell can deliver say 1 Amp at a particular Sun level 2 cells in parallel will deliver 2 Amps at the same Sun level. (More surface area = more current) (Parallel connection is when the + terminal of one cell is connected to the + terminal of the next cell and similar for the – terminal)
- The Open Circuit (or no load) Voltage of each cell varies only slightly with Sun level but the maximum current available (Amps) varies directly with Sun level. The brighter the Sun the more current is available.
- The maximum power will be obtained when the Sun strikes the cells at 90 degrees. (See test results later for an indication to effect of tilting panel.)
- Shading only one cell in a series array will reduce the power output significantly.
- Power = Volts x Amps (in watts)
- **Solar cells can only deliver current up to the limit imposed by the prevailing light level. If the electrical load (your motor) has a resistance so low that it wants more current than is available (ohms law applies V=R x I) the voltage of the cells will drop rapidly to near zero. Consequently the power delivered to the load (your motor) will be near zero.**

  FOR BEST RESULTS (maximum power transfer from panel to motor) IT IS CRITICAL TO MATCH THE LOAD TO THE SOLAR PANEL OUTPUT AVAILABLE AT THE PARTICULAR LIGHT LEVEL PREVAILING.

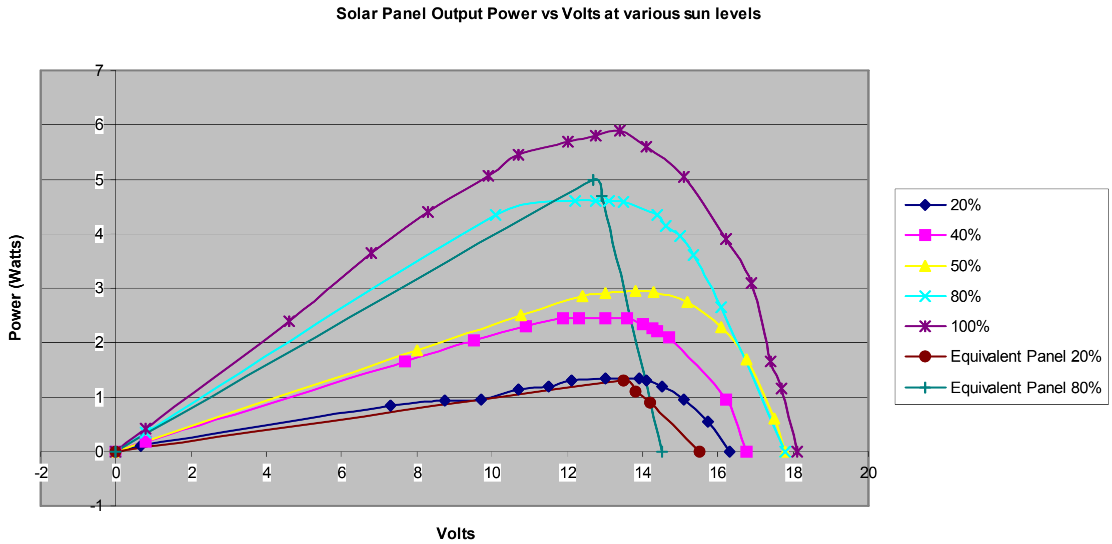
  TO IMPROVE THE LOAD MATCH CHANGING THE MOTOR, PROPELLER OR THE SOLAR PANEL CONFIGURATION ARE THE ONLY OPTIONS IN A DIRECT DRIVE CONFIGURATION WHEN ELECTRONICS ARE NOT USED.

  SOLAR PANEL CONFIGURATION COULD BE ----

  All cells in series.
  All cells in parallel
  A combination of series and parallel.

REMEMBER:
FREE RUNNING ON WATER TESTING OF THE COMPLETE BOAT IS THE ONLY ACCURATE WAY TO TEST.

The graph below shows the power output vs volts for a panel constructed from 12 Dick Smith segments each of 3 cells all wired in series. Note how the power peaks then drops off rapidly on both sides of the peak.
On the right hand side of the peak it is underloaded ie. a larger propeller or a propeller with more pitch is needed to increase the load and take advantage of the extra power available.
On the left hand side of the peak it is overloaded and a smaller propeller or a propeller with less pitch is needed to reduce the load and obtain more of the available power to drive the boat.



Changing the panel configuration to reduce the voltage and increase the current has a significant effect, as lower voltage reduces motor RPM which significantly drops the propeller load on the motor whilst the increase in current increases the available torque. Both these effects combine together to significantly change the operating parameters.

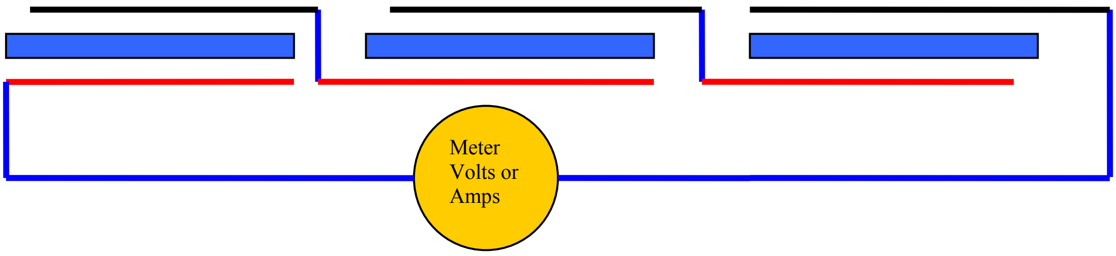
To help you in determining the load condition on your boat panel consider the following: The maximum power voltage for a silicon cell occurs at about 0.5 volt per cell. Using this figure the panel above with 30 cells in series would have maximum power occurring at about 15 volts. Examining the graph this is a fair average for all the sun levels. Consequently if you measure the voltage of your solar panel while the boat is running free in a pool (take care the leads from panel to voltmeter do not load the boat and tend to either pull it faster or slow it down) you

can easily tell if the panel is under or over loaded and consequently what actions you should take to improve the situation.

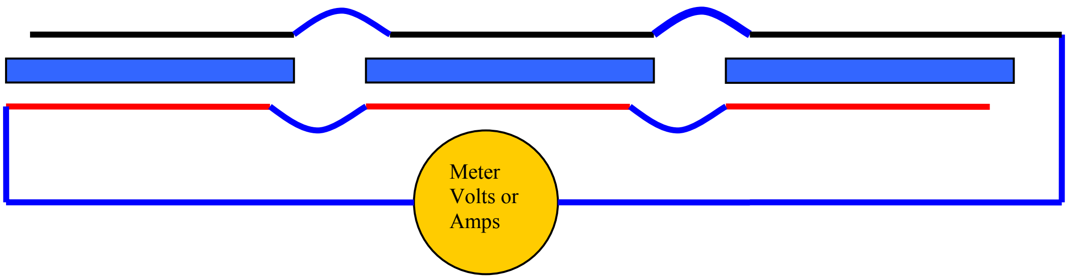
WIRING DETAILS & HINTS for SOLAR CELLS & MODULES

To help explain series and parallel connection of solar cells look at the following depiction. Remember the top surface of the cell is negative and the bottom surface is positive.

Top illustration cells connected in series
Bottom illustration cells connected in parallel



Series: cells connected positive to negative



Parallel: all cell positives connected together and all cell negatives connected together.

When cells are connected in series that is the +ve of one cell connected to the –ve of the next forming a "string" of cells, the voltages add. So two cells connected in series would have an output voltage twice the voltage of each cell alone. The current (amps) available remains the same as that available from individual cells.

When cells are connected in parallel that is all cell positives connected together and all cell negatives connected together the current available adds. So three identical cells connected in parallel would be able to deliver three times the current that each cell alone could deliver. The voltage however will remain the same at the voltage available from each cell.

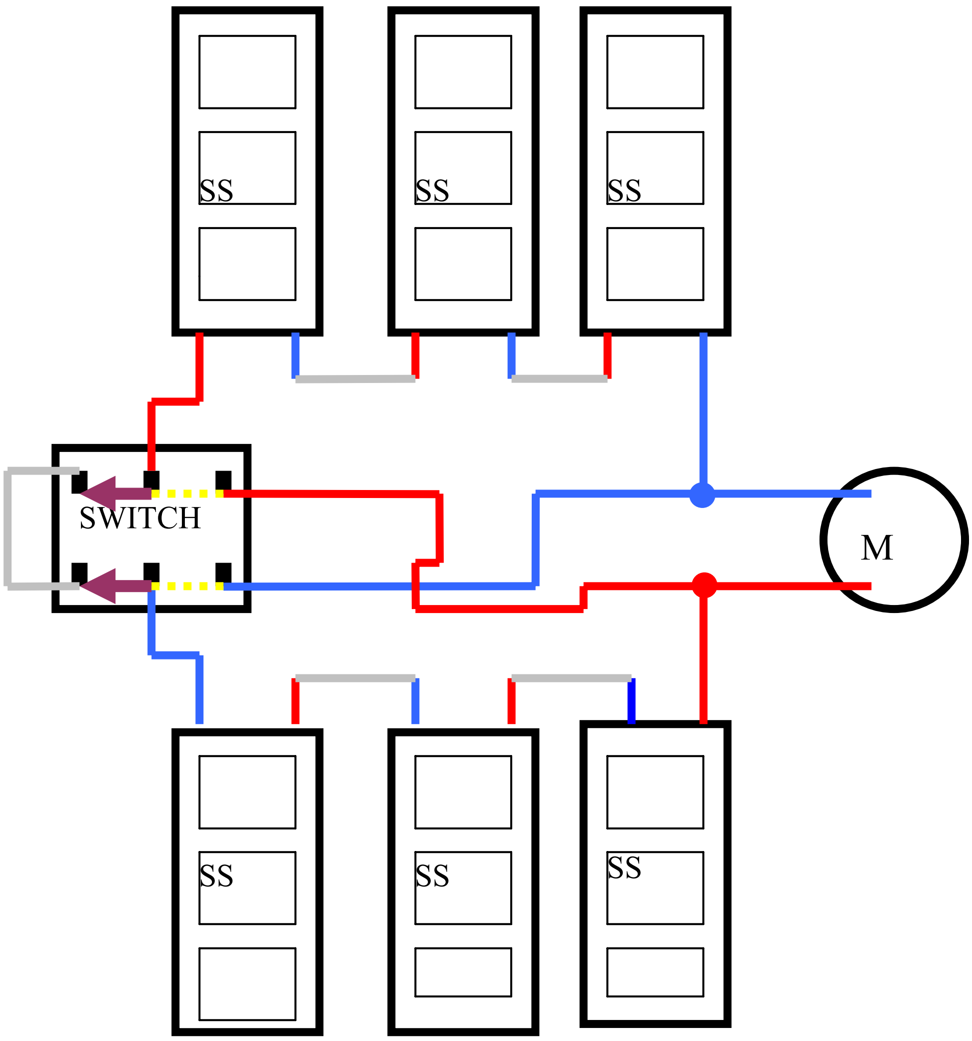
CIRCUIT TO CONNECT 6 3 CELL MODULES IN:

(Modules could be Dick smith Cam or Engelec or any other 3 cell segments)

A ALL SERIES

B 2 GROUPS OF 3 MODULES IN SERIES THEN PARALLELED

A circuit to achieve this by simple switching is shown below.



DRAWING LEGEND:

SWITCH Three Position double Pole Centre OFF

NOTE: SWITCH DRAWN in position to have all cells in series. the brown arrows show the connections made within the switch. The yellow dotted line shows the alternat connections made within the switch when it is switched to have the 2 groups of cells in parallel. When the switch is in centre position it is off and no connections are made within the switch.

To change motor direction of rotation reverse the positions of the wires on the motor terminals.

M is MOTOR SS Solar Modules Dick Smith Cat. O 2015

POSITIVE WIRES in RED NEGATIVE WIRES in BLUE

OTHER interconnecting wires GREY

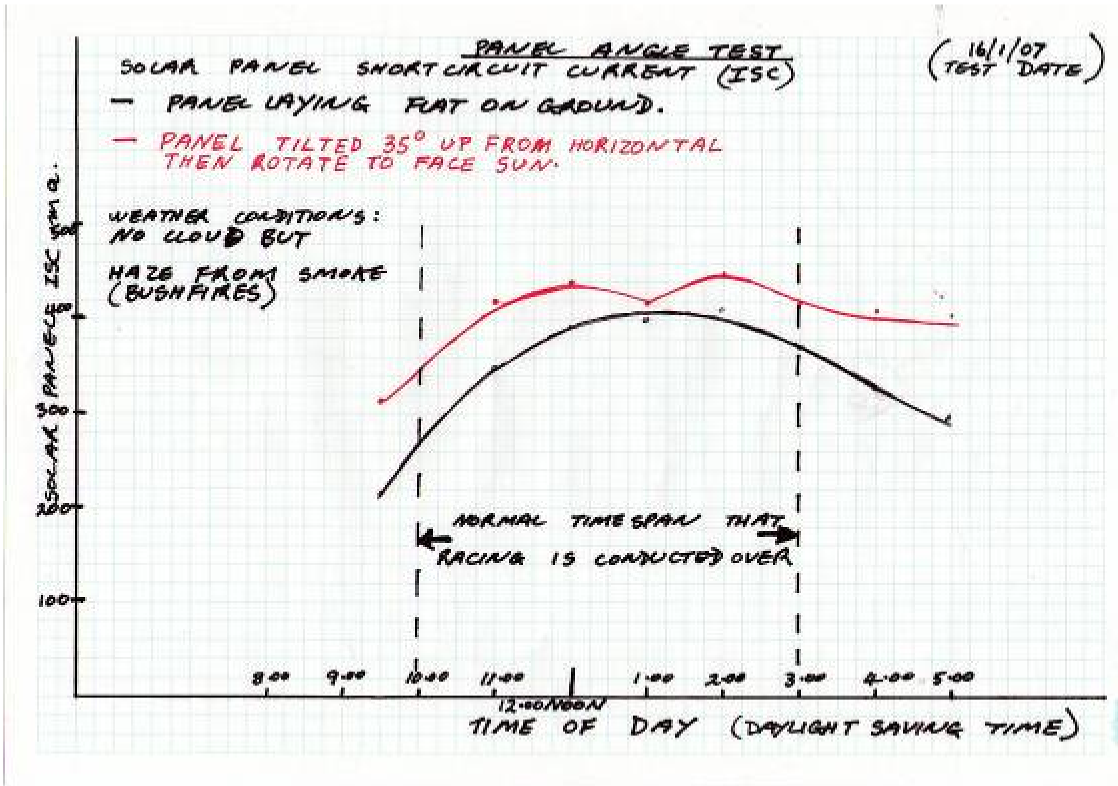
POWER VARIATION WITH PANEL ANGLE TO SUN:

Below is a table of power increase measured at different times of day (16/1/07 Daylight Saving Time) with the panel laying flat on the ground and then tilted 35 Degrees and rotated to directly face the Sun.
As the conditions were hazy due to high level smoke (bushfires) causing the available power to be variable the % increase in power has been used so as to give us a useful measure of any improvement .

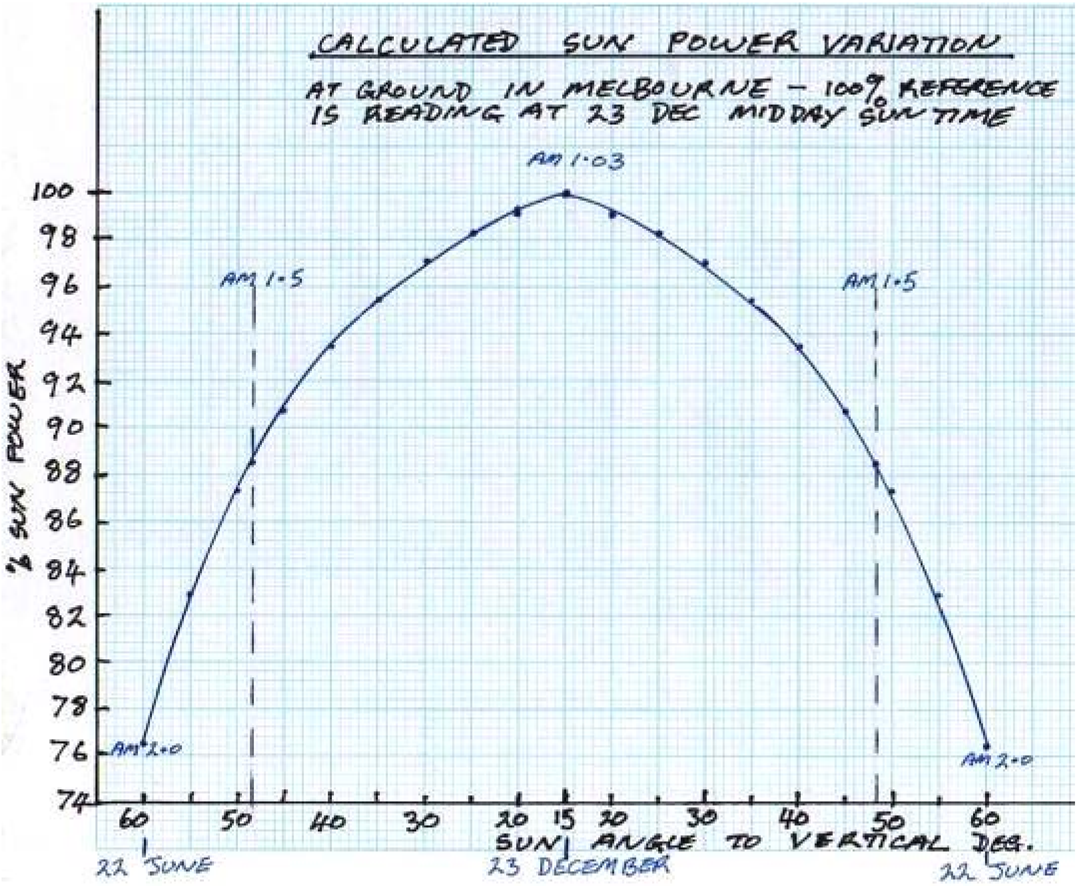
TIME	PANEL FLAT	PANEL TILTED	INCREASE
	ISC mA	ISC mA	%
9.30 am	225	320	42
11.00 am	350	425	21
12.00 noon	390	450	15
1.00 pm	400	420	5
2.00 pm	420	440	5
3.00 pm	370	425	15
4.00 pm	340	420	23
5.00 pm	300	420	40

Examination of these results shows that around the middle of the day there is some power gain to be had by facing the panel to the Sun. The gains increase significantly the further away we get from midday.
Most racing occurs in the time span of 11.00 am to 3.30 pm . At either end of this time span a 20% increase in power is possible by facing the panel to the Sun.
Many competitors already do this **CAN YOU AFFORD NOT TO.**
CAUTION: A Panel at an angle acts like a sail it will increase air drag and in a strong head wind your boat may even be blown backwards.

Shown below is the data presented above but in graphical form.



The Sun levels also vary over the year following is a graph showing the calculated variation. Note the lowest value is AM 2.0 which represents the power at the earth surface after the light has passed through twice the thickness of the atmosphere. This is the situation in Melbourne in mid winter.



POSSIBLE TESTING:

- Check the short circuit current available from a cell at various Sun levels (use a multimeter on the current or amps range)
- Check the short circuit current variation from a cell as you face it towards the sun and then slowly turn it away from the Sun.
- Connect cells in series and measure the open circuit Voltage as more cells are added.
- Connect cells in parallel and measure the short circuit current as cells are added.
- Shade one cell in an array, observe the reduction in short circuit current

WIRING:

- Keep wiring neat and well laid out.
- Colour code wiring, the convention is Black for Negative and Red for Positive.
- Insulate any bare wires that could touch and short circuit.
- Secure wires that could move and fracture either themselves or other components such as switch or motor terminals.
- Make certain all connections are tight making good electrical contact and cannot work loose during operation.

MOTOR:

This type of DC motor is essentially driven by magnetic attraction and repulsion between the permanent magnets in the motor stator (case) and the rotor which is an electromagnet powered by your solar panel.

- Motor RPM (revolutions per minute) varies directly with Voltage.
- Torque (twisting force on the motor shaft) varies directly with current (Amps)
- **The slower a motor is turning (lower RPM) the lower will be its electrical resistance , and consequently the chance of overloading the solar panel is increased. SEE DESCRIPTION IN SOLAR CELLS . To overcome this problem we can reduce the motor load and let it speed up by switching to a smaller propeller or make more current available by changing the solar panel configuration to series and parallel.** (This change of panel configuration reduces voltage which slows the motor. A slower propeller speed significantly reduces power required to drive it. So we tend to see a double effect from only this one change)
- **Matching the motor load to the available panel output is critical for best performance.**

COUPLING:

Connecting the motor to the propeller is essential if our boat is to go. This area has the potential for high loss of power if not done correctly. Alignment of the motor and propeller shaft is critical if losses are to be minimised , once obtained this alignment must be maintained at all times. Your boat design and construction must achieve this.

Testing has shown that a soft silicon rubber tube coupling tolerated slight alignment errors without measurable power loss , but a harder PVC tube coupling had higher losses.

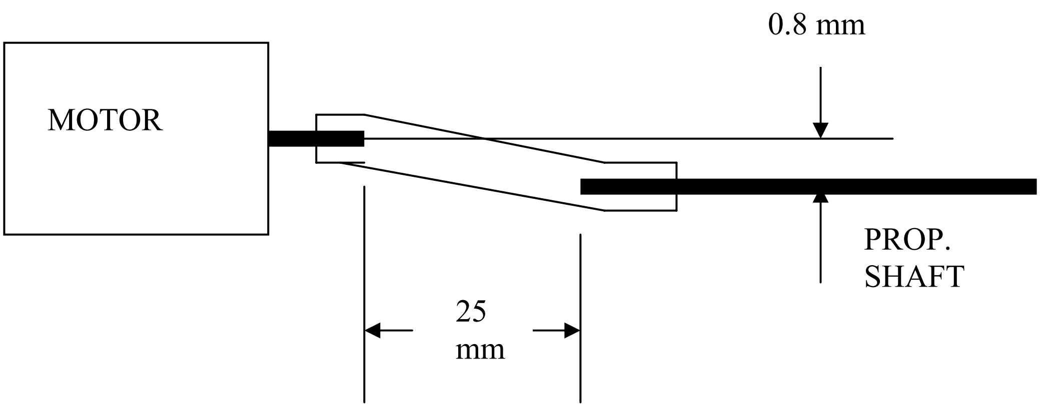
COUPLING:

POSSIBLE TESTING:

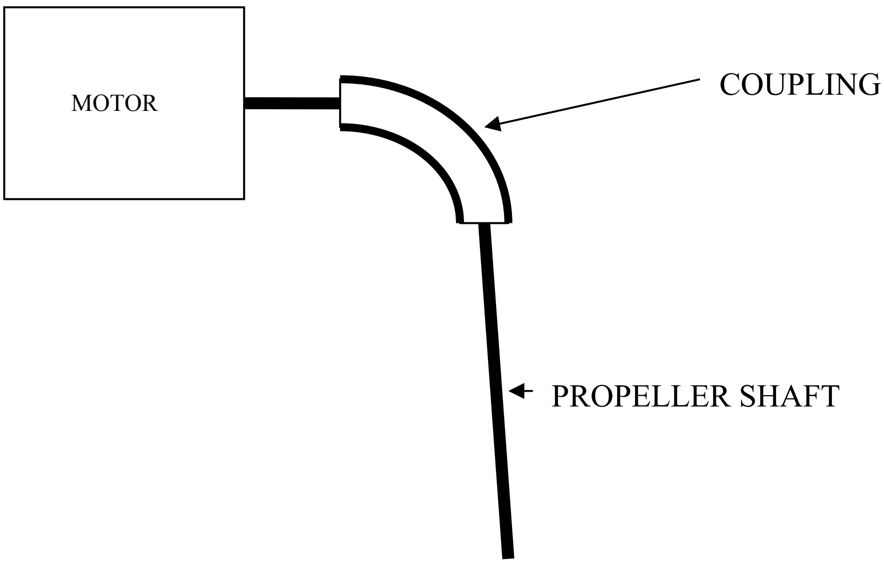
To determine the difference between couplings when alignment of motor and propeller shaft is not "perfect"

Two misalignment cases are suggested.

Case one, motor and propeller shaft parallel but vertically shifted by 0.8mm



Case Two: The motor and propeller shafts at an angle to each other but extensions of the shaft lines would intersect. I suggest testing up to 90 Degrees out of alignment.



Test by running the motor from a battery supply using 2 cells in series giving 3 Volts and note the current required by the motor. This is an indication of the power required. You can test both the soft and hard tube coupling as well as the effect of alignment.

COMPLETE BOAT:

TESTING:

Test boat in pool with different propellers, motor and solar panel configuration ie. all cells in series and a combination of series and parallel at different Sun levels.
Record the results of time taken to travel a set distance and the Sun level .
From these results decide the best configuration for different Sun levels.
Use this data to set your boat up on race day.

Note: Test with boat running free if possible as static testing loads the Motor more than free running. Free running tests will give more relevant data.

APPENDIX 1: MEASURING SUN LEVELS

Many references are made in this document about Sun levels. Your ability to measure them is critical to making sense of any testing.
DO NOT USE AN ORDINARY LIGHT METER these are typically set up to respond to the light frequencies the human eye is sensitive to.
Silicon solar cells respond to different frequencies so readings taken on an ordinary light meter will not be relevant to their performance.

I suggest you construct a meter for your own use .
It is very simply done only one solar segment Dick Smith Cat. No O 2015 and any multimeter capable of mearuring from 0 to 100ma. is required.

The solar segments output terminals are connected directly to the multimeter test leads. Positive to positive and negative to negative.
The meter is switched to the ma. range and the output of the solar segment adjusted to 100 ma. in full Sun by partially covering it with tape or any material that stops sunlight reaching the cells.
We now have a meter that reads Sun level in %. It responds exactly the same as our silicon solar panel as it is a silicon solar cell.

Calibration is the most difficult thing about this meter WHEN IS IT 100% SUN?? around midday when the sky is clear between November and February is best.
Make sure to point the solar segment directly at the sun (angle of incidence 90 degrees)
However for your testing it does not matter if the meter is not calibrated to exactly 100% Sun so long as you conduct all tests using the same meter and do all set ups on race day using the same meter everything will be ok.

The photograph below shows how I set up such a meter to record sun levels during races at the Victorian event.

On the left is a standard solar segment for comparison. In the centre is the partly covered segment which has been mounted on a piece of timber for convenience. On the right is the multimeter

NOTE: Scorpio technology have a calibrated solar segment which delivers 100 milli amps in full Sun. This is designed to be connected to the current input of a multi meter on the milli amp range to read Sun % direct as it is calibrated to read 1 milli amp for each 1% of Sun.

APPENDIX 2:

SUPPLIERS LIST

SUPPLIER	COMPONENTS SOLAR PANELS	MOTORS	PROPELLERS
CAM Art Craft & Technology www.camartech.com.au	YES	YES (incl. Faulhaber) & Electronic panel power controllers	YES
Hobby shops various		YES	YES
Scorpio Technology Vic P/L www.scorpiotechnology.com.au	YES	YES & Electronic panel power controllers	YES
Tony Bazouni Tel: 0403 665577	Automax electronics MPP tracking		
Float a boat info@floataboat.com.au		YES	YES
Miniature Steam (Live steam supplies) www.miniaturesteammodels.com			YES
R & I Instrument and Gear Co www.rigear.com.au	Gear reduction drive system		

APPENDIX 3:

DEMONSTRATION BOAT
(Built specifically for demonstration at Workshops)

The selection of components was based on choosing components that when correctly assembled would yield a boat that would run under most conditions. (See table 1 for static thrust measurements taken when testing a drive unit constructed from these components.)
This is critical particularly for first time builders where a boat that does not run has an extremely negative effect.
NOTE: Performance data given here should be used as a guide only, actual performance will vary due to build standard and characteristics of individual components **ALWAYS** test your boat to determine the best settings for it.

TEST RESULTS STATIC THRUST AT VARIOUS SUN LEVELS

% SUN	PANEL IN PARALLEL	PANEL IN SERIES
20	23 gm	8 gm
40	31 gm	22 gm
60	33 gm	41 gm
80	33 gm	55 gm
100	34 gm	70 gm

TABLE 1

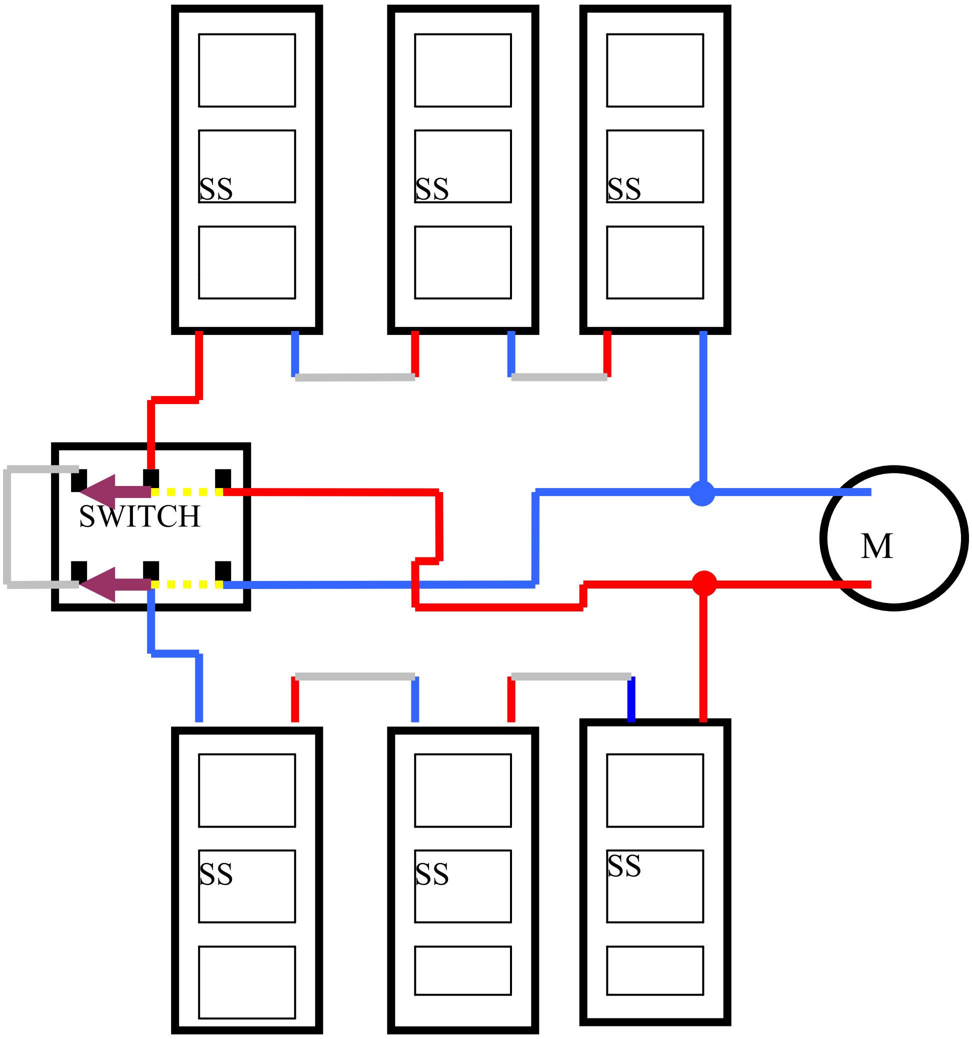
NOTE: Static thrust was measured in these tests. The thrust delivered by the propeller when your boat is moving through the water will be less than the static thrust due to the effect of the boats forward speed.
Because of this effect it is quite possible that the use of a larger propeller will give better performance on a boat moving through the water than the smaller propeller used in the above tests.
Test your boat when running free to determine the exact best Sun level to change the panel configuration from series to series and parallel and which propeller is the best at the different sun levels and panel configurations.

The larger propeller I suggest testing is a 40 mm. Diameter version of the 30 mm. Propeller tested here or the 2 blade 30 mm diameter Scorpio propeller. The solar motor stocked by Scorpio should also be tested as it has given excellent results particularly in conjunction with the Scorpio Solar Panel.
The Radio Active part number for the larger diameter propeller together with a shaft and tube (ie. A PROPSHAFT ASSEMBLY) is MA 3052 I think the part number for a propeller on its own is MA 3045 but check this.

SOLAR PANEL:
From table 1 it can be seen that in order to obtain the highest thrust possible the solar panel must be configured to suit the Sun level.

For maximum static thrust the Solar Panel is configured:
For Sun levels above 40% all cells in series which gives a nominal Short Circuit Current of 500ma with Open Circuit Volts of about 10.5 Volts in full Sun.
For Sun levels below 40% , 2 groups of 3 cells in series, these are then parallelled which gives a nominal Short Circuit Current of 1000ma with an Open Circuit Voltage of about 5.75 Volts in full Sun.

SEE DIAGRAM FOLLOWING FOR HOW TO WIRE SWITCH AND SOLAR MODULES TO ACHIEVE THIS.



DRAWING LEGEND:

SWITCH Three Position double Pole Centre OFF

NOTE: SWITCH DRAWN in position to have all cells in series the brown arrows show the connections made within the switch The yellow dotted line shows the alternate connections made within the switch when it is switched to the 2 groups of cells in parallel. When the switch is in centre position it is off and no connections are made within the switch To change motor direction of rotation reverse the positions of the wires on the motor terminals.

M is MOTOR

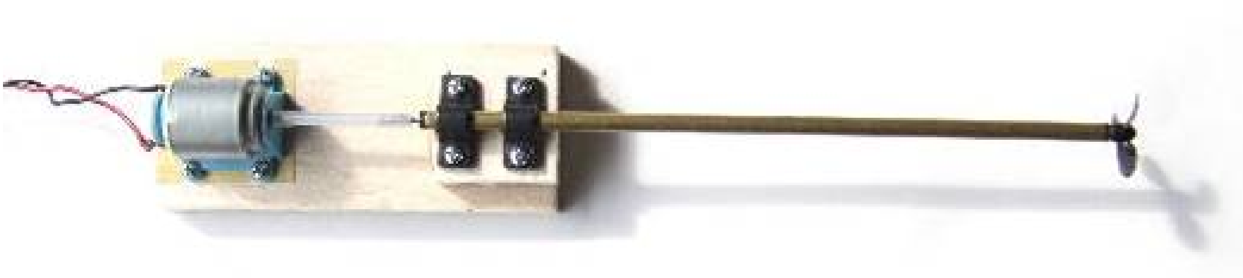
SS Solar Modules

POSITIVE WIRES shown in RED

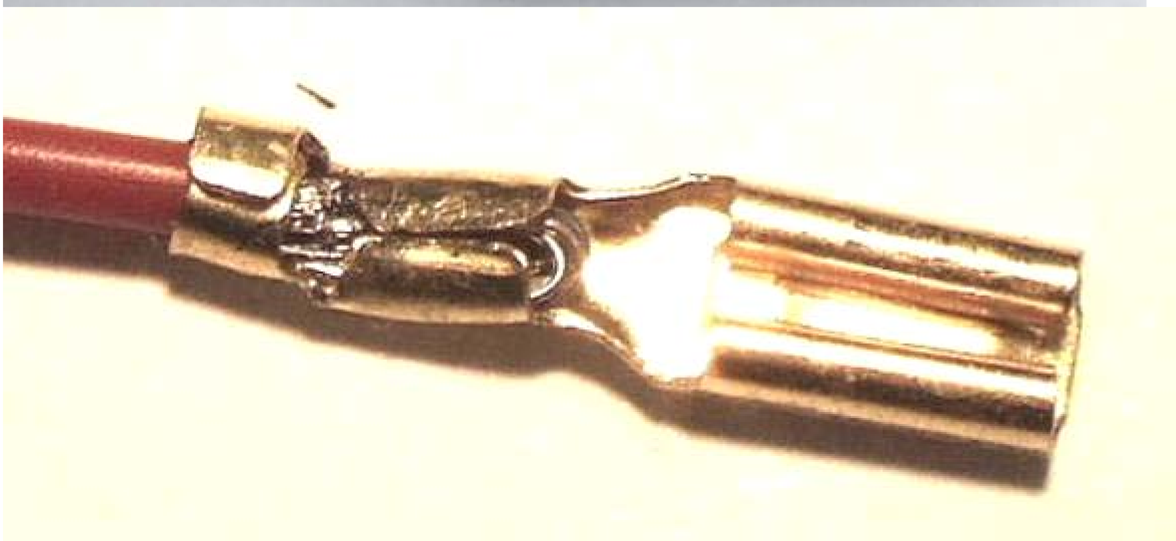
NEGATIVE WIRES shown in BLUE

OTHER interconnecting wires GREY

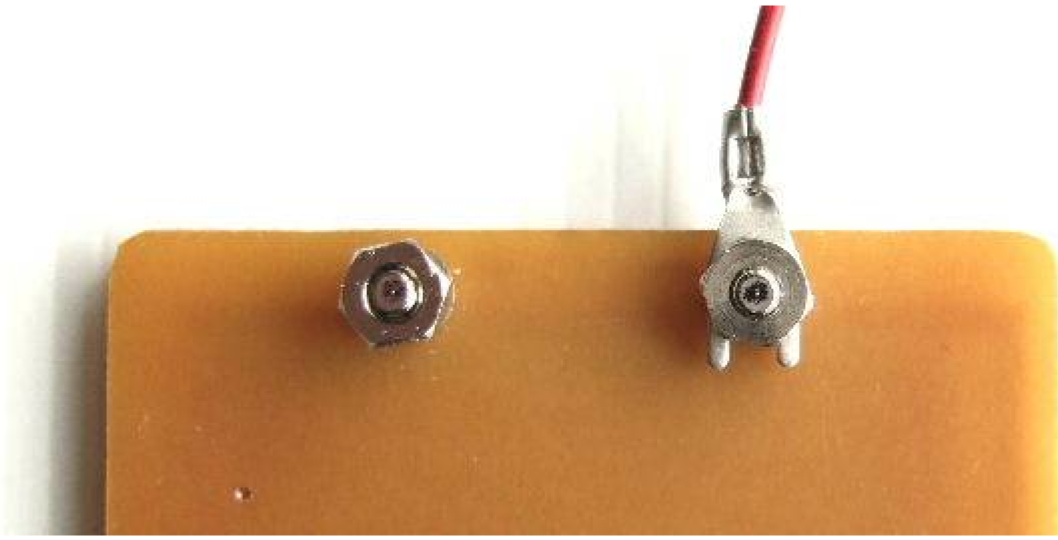
DRIVE COMPONENTS:
Photographs of the drive components assembled together are shown below.
You may wish to use this method of mounting motor and propeller shaft assembly. The balsa wood block holding the motor and shaft in alignment can then be secured to the boat. This technique makes it easy to align motor and shaft and maintain this alignment. Poor alignment will reduce the power transferred to the propeller and slow the boat down.
Obviously there are many ways to mount the components, however you do it ensure good alignment is maintained constantly.
HINT: Lubricate the propeller shaft where it rotates in the plastic bearings at each end of the brass tube with a small quantity of light oil. (sewing machine oil or similar is satisfactory) This will reduce friction and increase the power available to drive your boat. BE CAUTIOUS too much oil on the shaft under the coupling may cause slipping between the coupling and propeller shaft.



ELECTRICAL WIRING:
Colour code your wires Red for Positive and Black for Negative is the convention. By doing this you make it easier to follow the circuit diagram and very much easier for trouble shooting. Trying to find and fix a problem when confronted by a birds nest of identical wires is frustrating and wastes a lot of time.
Connections can be made by soldering, this is usually best, however I have shown the use of crimped fittings and recommend their use in this case. The crimped fittings allow wires to be simply unplugged and replugged for modifications. Not using a soldering iron is much safer for small hands and fingers.
Take care to secure all wires so they will not wobble around and break the terminals off, a particular problem with the very thin motor terminals. If there is any chance of bare wires or terminals touching each other insulate them with tape.
Following are some photographs of wiring to guide you.



Shown above are the two types of lugs used , the forked lug is used to connect to the solar segments the brass spade lug is used elsewhere.



Forked lug connected to the solar segment terminal.

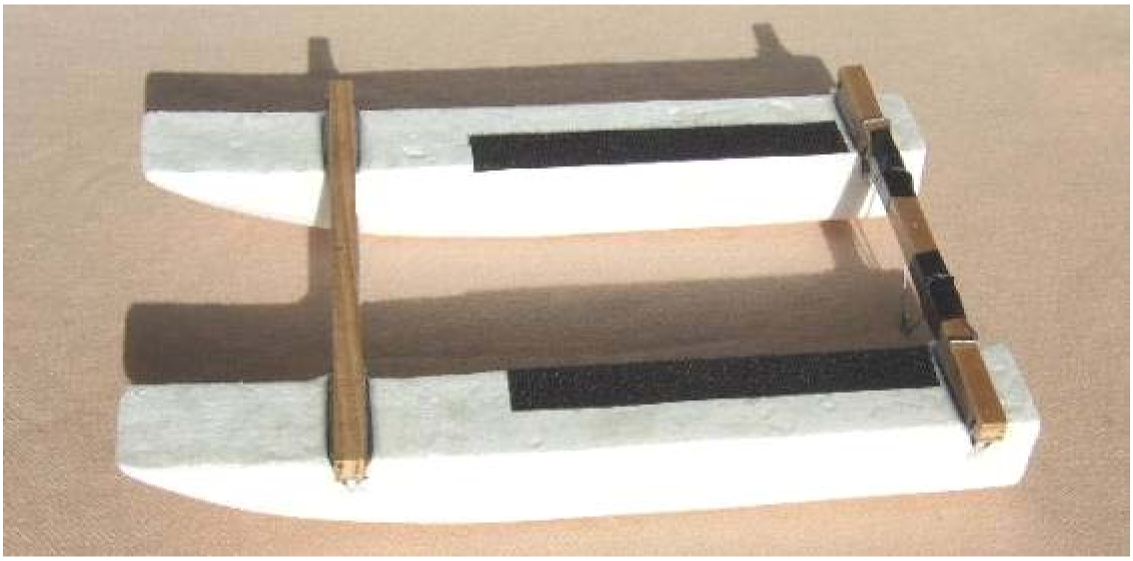
Lug and wire attached to switch

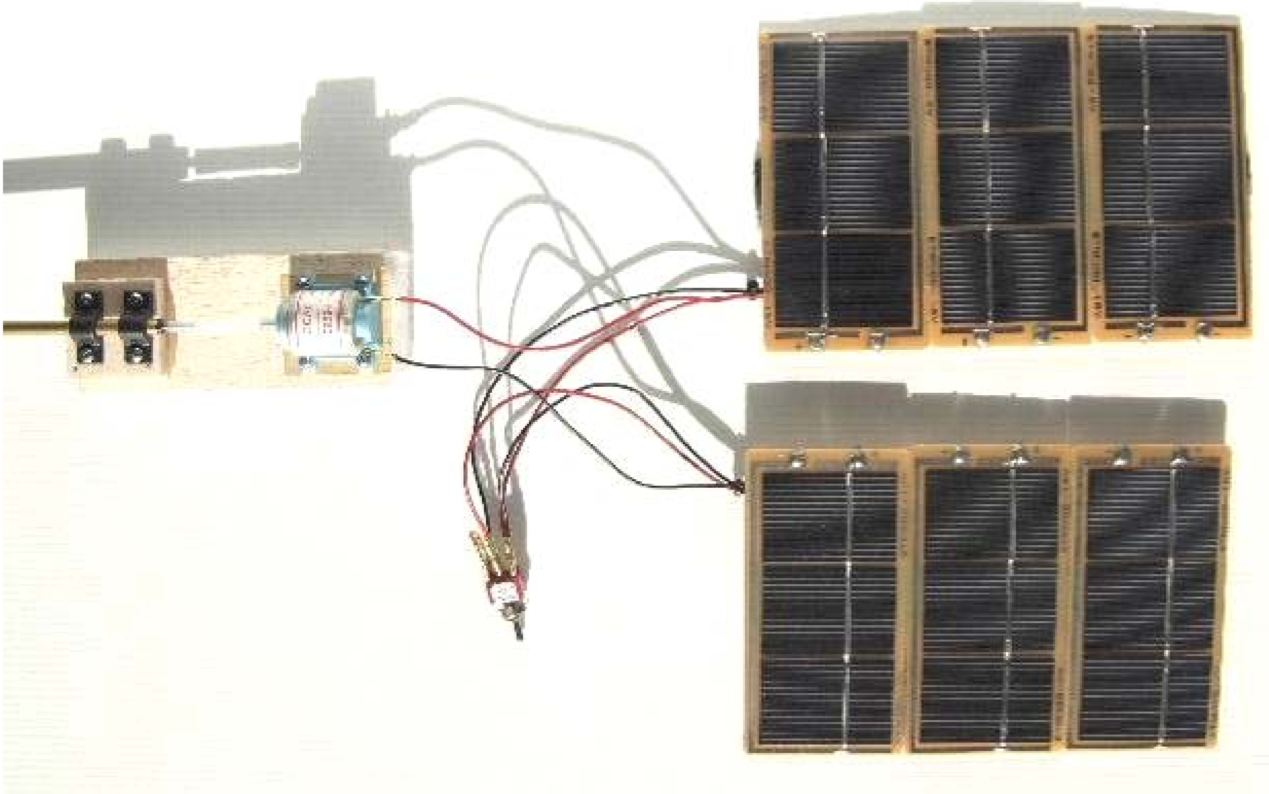
Motor terminal on the Dick Smith motor is very thin in order for the lug to grip it tightly gently close down both sides of the lug by squeezing each side in turn using a pair of pliers. For the scorpio motor and many others the lugs are much thicker and the lugs will fit without modification.

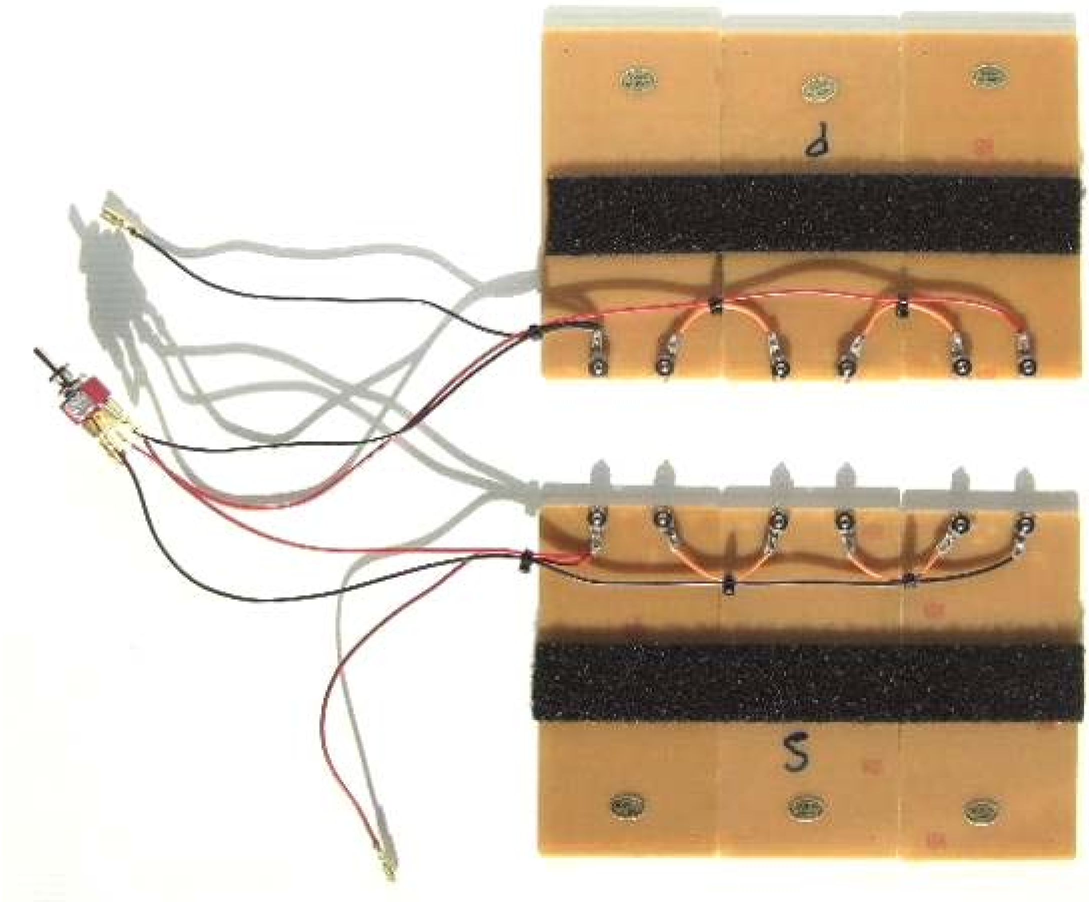
Dick Smith Motor rear view showing a lug fitted to one terminal. The rolled section of the lug must face inwards to allow the turned over edges of the motor terminal to fit into the lug. NOTE: This motor is no longer available use one from CAM or Scorpio

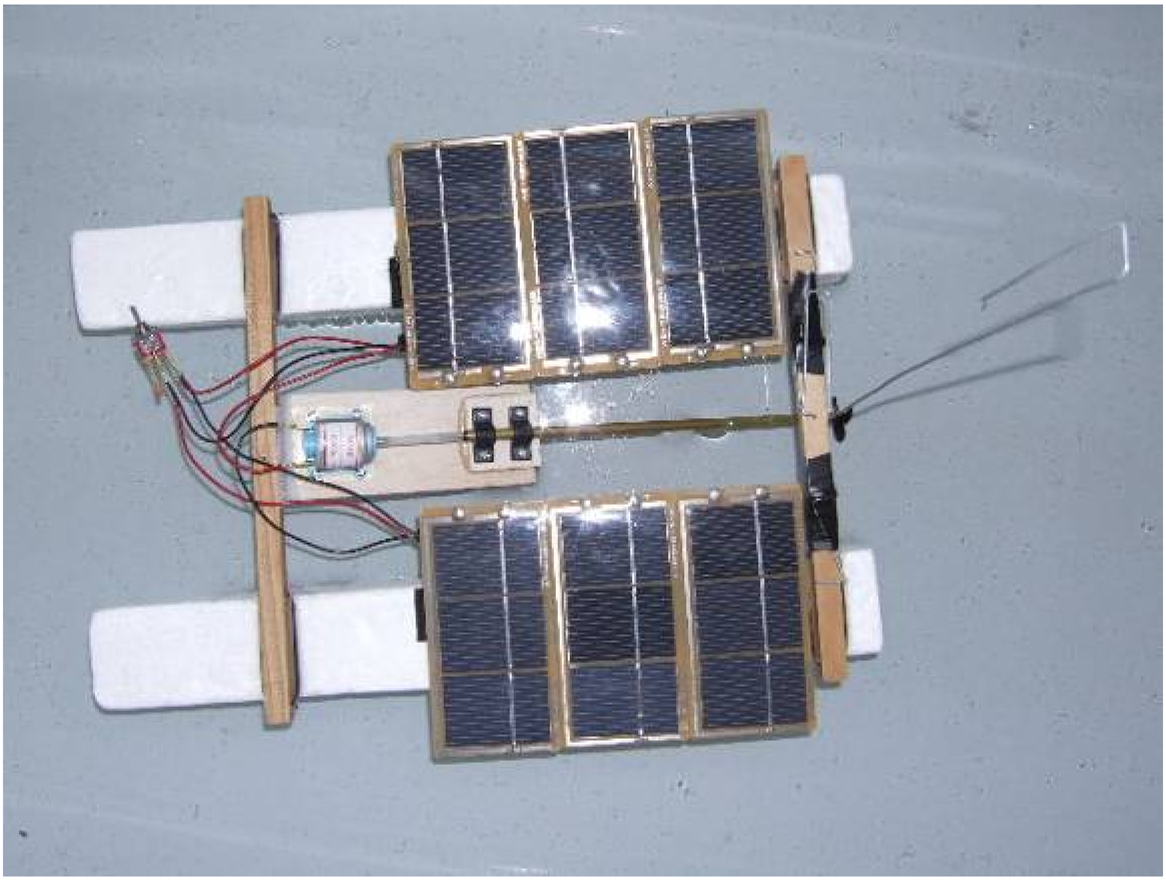
Rear view of motor with wires attached and secured to motor body with tape to prevent breaking the motor terminals by wire movement.

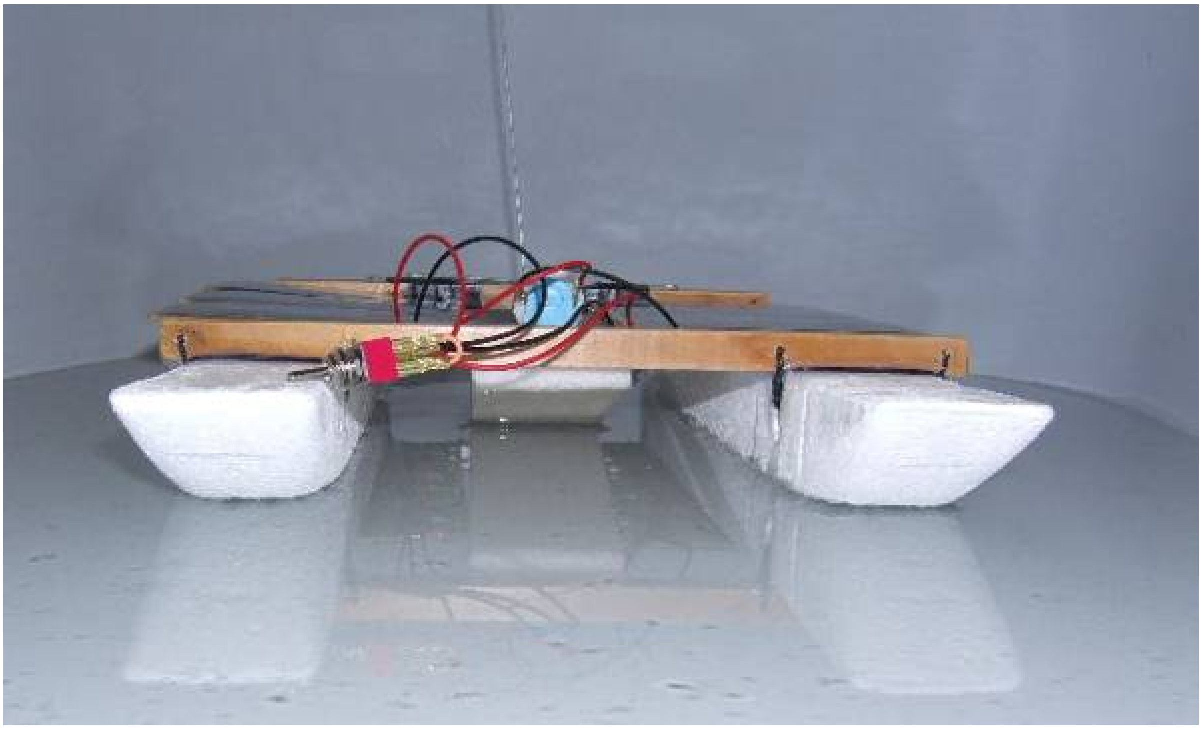
FOLLOWING ARE PHOTOGRAPHS OF THE SAMPLE BOAT CONSTRUCTED USING THESE COMPONENTS

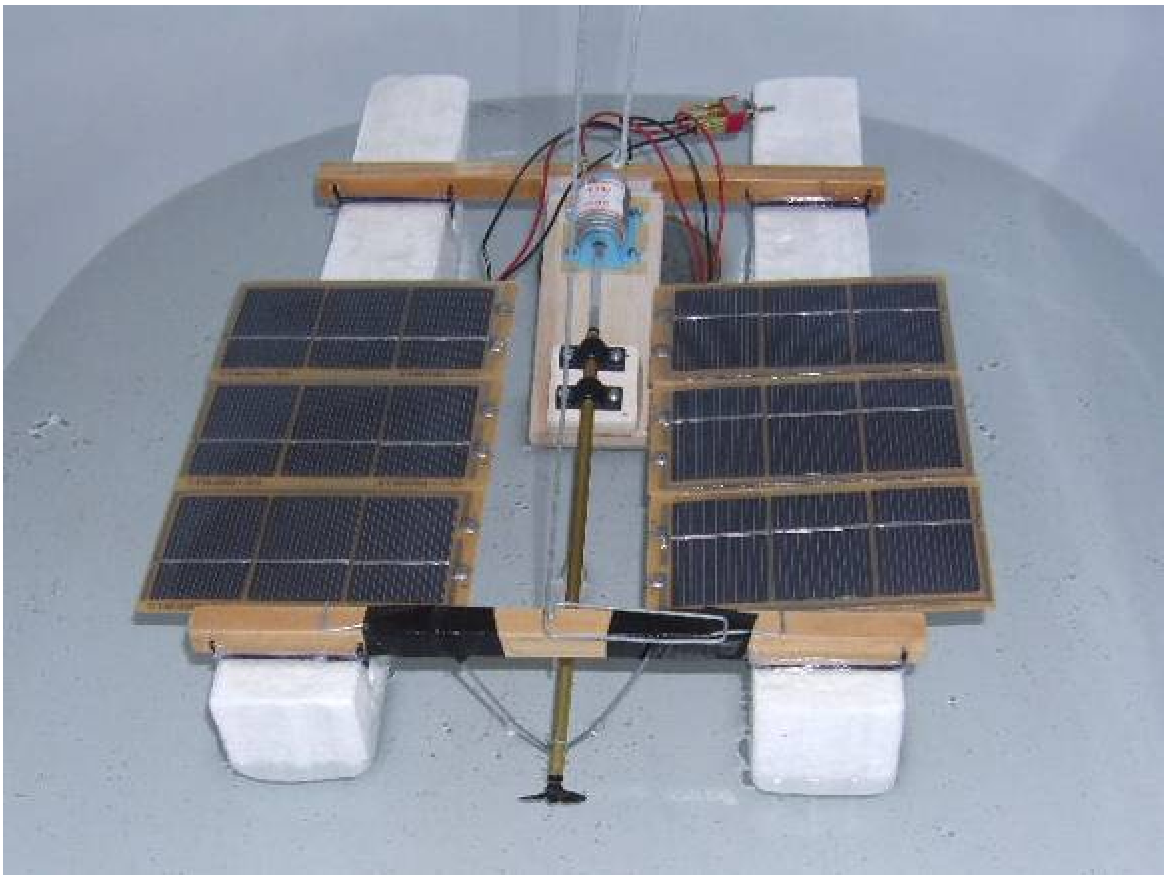


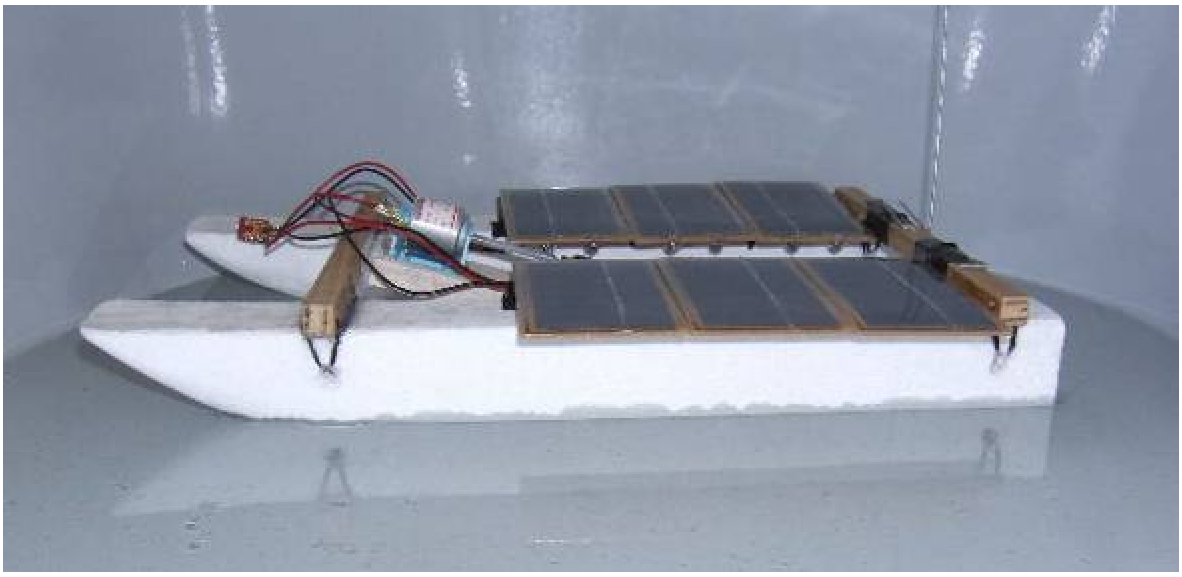


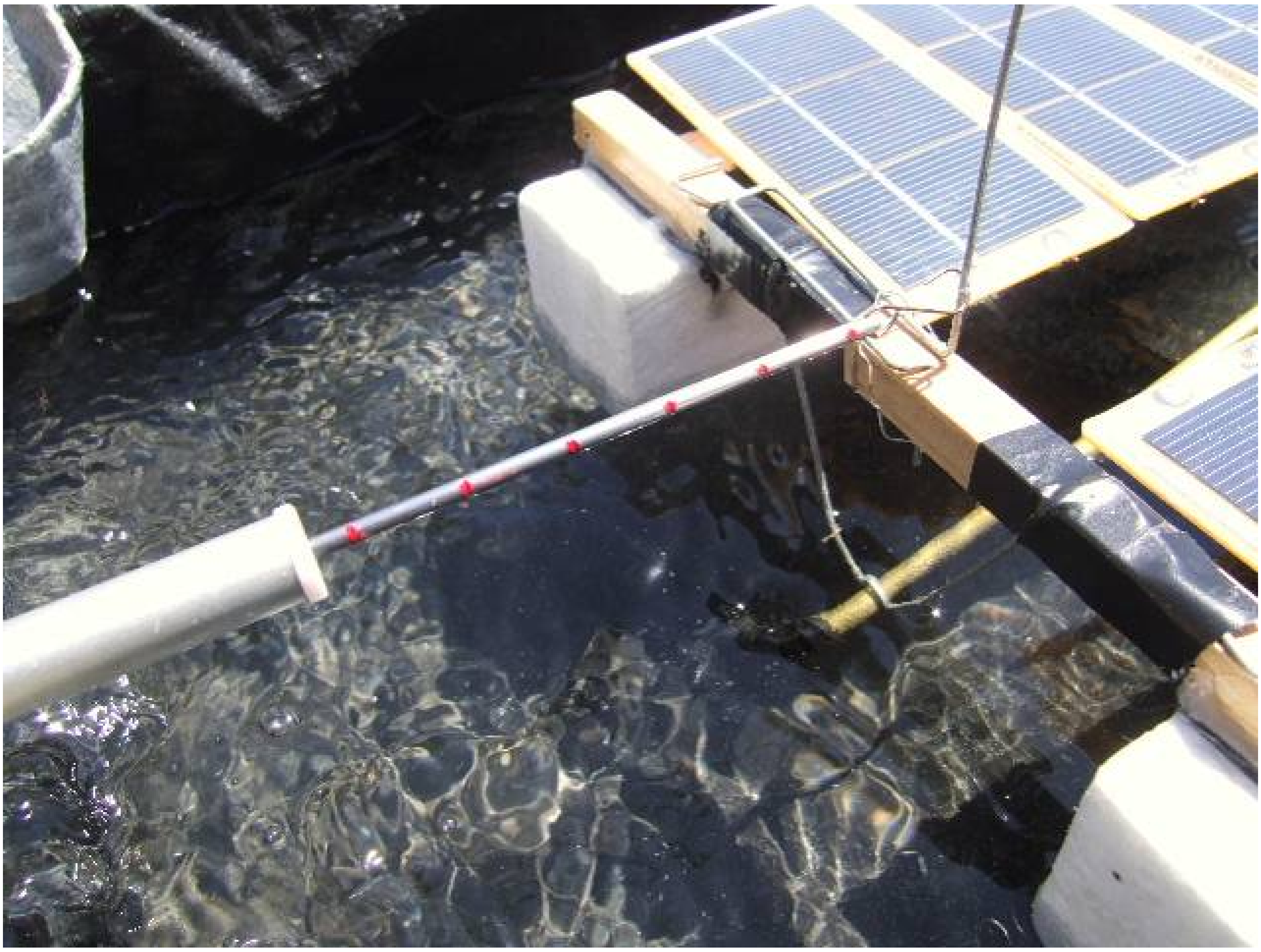








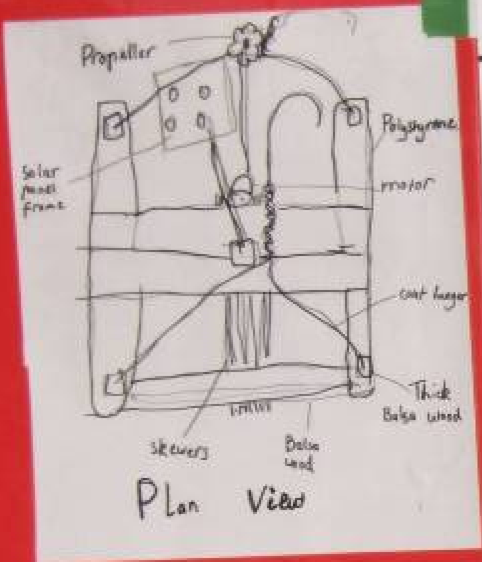




APPENDIX 5: PHOTOGRAPHS OF BOAT POSTERS

The following photographs of posters are included to give an idea as to typical good boat posters.

THE ITALIAN ROCKET



Designed by :
Hamish Russell
Hugh Neerhut
Keaghan Kennedy

Tools and materials used :

- . Solder
- . Scissors
- . Hot glue gun
- . Drill
- . Balsa wood
- . Polystyrene
- . Glue (Normal type)
- . Wire cutter
- . Motor
- . Paint brush
- . Saw
- . Paint
- . Sequins
- . Brass rod
- . Velcro
- . Skewers
- . Wire
- . Propeller

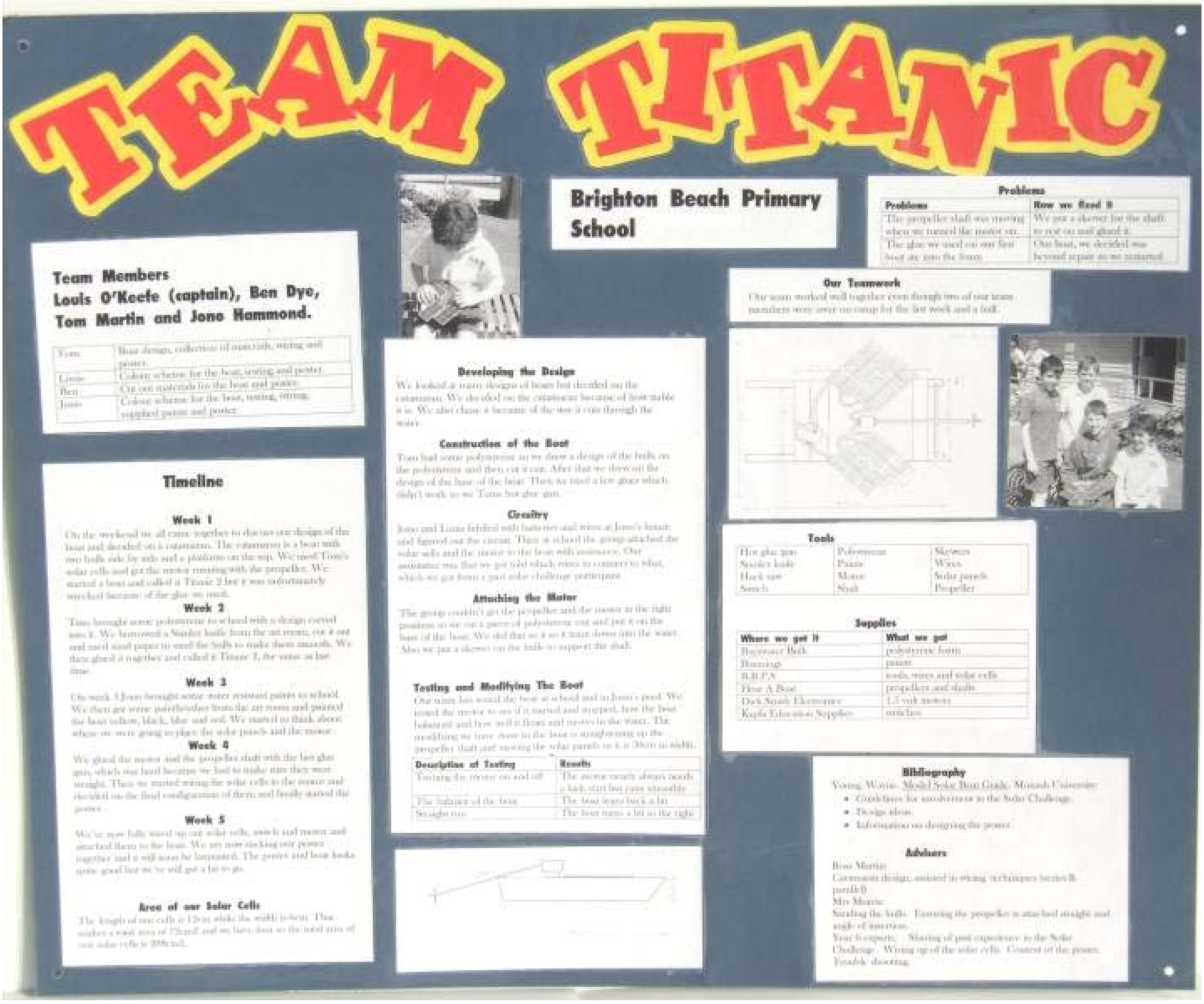
How to construct an Italian Rocket :

. Cut a piece of polystyrene into two pieces, then get sand paper then draw a curve onto both pieces.
. Join the two polystyrene pieces together using three pieces of balsa wood.
. Put four pieces of thick balsa wood on the two polystyrene pieces to fix the coat hanger, which helps guide the boat.
. Make a frame using balsa wood and a brass rod to support the solar panel.
. Decorate it as you like.

Helpers:
Mr. A (Teacher)
Mrs. Julie Fagan (Teacher)
Nathan (Teacher)
Liam Watson (Student)

How we tested it
We tested our boat in the outdoor pool at the Geelong collage preparatory school with a battery pack and a solar panel. Our boat was too wobbly that it tipped over.

The Geelong College
Year 4


TEAM TITANIC
Brighton Beach Primary School
Team Members
Louis O'Keefe (captain), Ben Dye, Tom Martin and Jono Hammond.
Timeline
Week 1
Week 2
Week 3
Week 4
Week 5
Area of our Solar Cells
Developing the Design
Construction of the Boat
Circuitry
Attaching the Motor
Testing and Modifying The Boat
Description of Testing
Results
Problems
How we fixed it
Our Teamwork
Tools
Hot glue gun
Stanley knife
Hack saw
Switch
Polystyrene
Paints
Motor
Shaft
Skewers
Wires
Solar panels
Propeller
Supplies
Where we got it
What we got
Bibliography
Advisers

APPENDIX 6:
Propeller data Radio Active England
http//www.radioactivemfg.com/Catalogue/p14.htm

Product Profile

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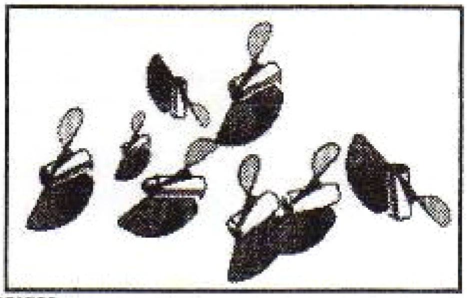
Specialist in Model Accessories

BOAT PROPELLERS
Standard and "X" ranges available in M5 and M4 threads.
Moulded in red nylon and black glass filled nylon.



BOAT PROPS "X" RANGE COMPLETE WITH BRASS BUSH
(GLASS FILLED NYLON)

MA3001	35X M5	**MA3007**	35X M4.
MA3002	40X M5	**MA3008**	40X M4.
MA3003	45XM5.	**MA3009**	45X M4.
MA3004	50X M5.	**MA3010**	50X M4.
MA3005	52.5X M5.	**MA3011**	52.5X M4.
MA3006	55X M5.	**MA3012**	55X M4.

(RED NYLON)

MA3013	35X M5.	**MA3019**	35X M4.
MA3014	40X M5.	**MA3020**	40X M4.
MA3015	45X M5.	**MA3021**	45X M4.
MA3016	50X M5.	**MA3022**	50X M4.
MA3017	52.5X M5.	**MA3023**	52.5X M4.
MA3018	55X M5.	**MA3024**	55X M4.

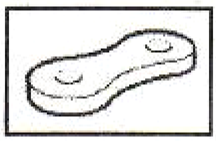
BOAT PROPS STANDARD RANGE COMPLETE WITH BRASS BUSH
(GLASS FILLED NYLON)

MA3025	35SR M5	**MA3030**	35SR M4.
MA3026	40SR M5	**MA3031**	40SR M4.
MA3027	45SR M5.	**MA3032**	45SR M4.
MA3028	50SR M5.	**MA3033**	50SR M4.
MA3029	55SR M5.	**MA3034**	55SR M4.
MA3070	62SR M5.	**MA3075**	62SR M4.

(RED NYLON)

MA3035	35SR M5	**MA3040**	35SR M4.
MA3036	40SR M5	**MA3041**	40SR M4.
MA3037	45SR M5.	**MA3042**	45SR M4.
MA3038	50SR M5.	**MA3043**	50SR M4.
MA3039	55SR M5.	**MA3044**	55SR M4.
MA3080	62SR M5.	**MA3085**	62SR M4.

MA3090 WHITE NYLON RIGGING BOWSIE 15mm long.



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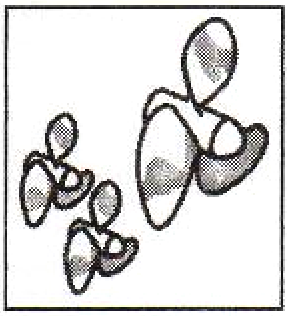
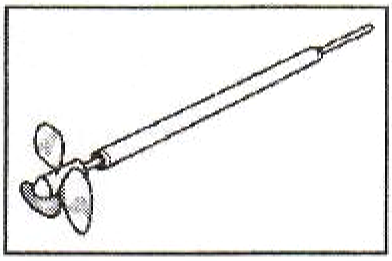
Specialist in Model Accessories

THREE BLADED *(GLASS FILLED NYLON)*
MA3045/M2 40 mm.dia.
MA3045/M4 40 mm.dia.
MA3045/A 30 mm.dia.



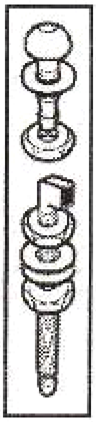
TWO BLADED DOG DRIVE BOAT PROPELLERS 3/16" SHAFT
(GLASS FILLED NYLON)
MA3001DD-35X
MA3002DD-40X
MA3003DD-45X
MA3004DD-50X
MA3005DD-52.5X
MA3006DD-55X
MA3025DD-35SR
MA3026DD-40SR
MA3027DD-45SR
MA3028DD-50SR
MA3029DD-55SR

JUNIOR PROPSHAFT ASSEMBLIES
Brass tube with C/F nylon bearings.
All have M2 threaded brass inserts. G/F nylon props, ideal for electrically powered boats.

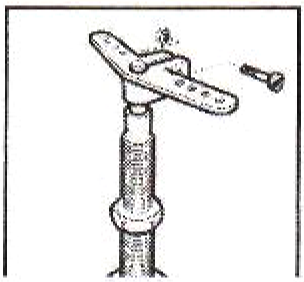


MA3046 30mm. 3 bladed prop. 6" (153mm.) tube.
MA3047 30mm. 3 bladed prop. 7" (178mm.) tube.
MA3048 30mm. 3 bladed prop. 8" (203mm.) tube.
MA3049 30mm. 3 bladed prop. 9" (229mm.) tube.
MA3050 40mm. 3 bladed prop. 6" (153mm.) tube.
MA3051 40mm. 3 bladed prop. 7" (178mm.) tube.
MA3052 40mm. 3 bladed prop. 8" (203mm.) tube.
MA3053 40mm. 3 bladed prop. 9" (229mm.) tube.

WATER SCOOP AND OUTLET
Made in glass-filled nylon complete with nuts and seals, moulded nipples to accept tubing.
MA3058 Water Scoop
MA3059 Water Outlet
MA3060 Both Water Scoop and Outlet.



RUDDER AND SHAFT UNIT
This comprises of a brass rudder riveted to shaft. Glass filled nylon outer bearing, brass nut and washer, rubber sealing ring, glass-filled tiller arm with clamp fitting.
MA3061 Micro rudder blade.
MA3062 Mini rudder blade.
MA3063 Small rudder blade.
MA3064 Medium rudder blade.
MA3065 Large rudder blade.
MA3066 Extra large rudder blade.



APPENDIX 7:

This appendix contains data already included in the Master Workshop document above, it was produced specifically to provide a brief guide to first time supervisors so they can guide their students towards a boat that functions.

MODEL SOLAR BOAT

PROPULSION SYSTEM--- SUGGESTED STARTING POINT

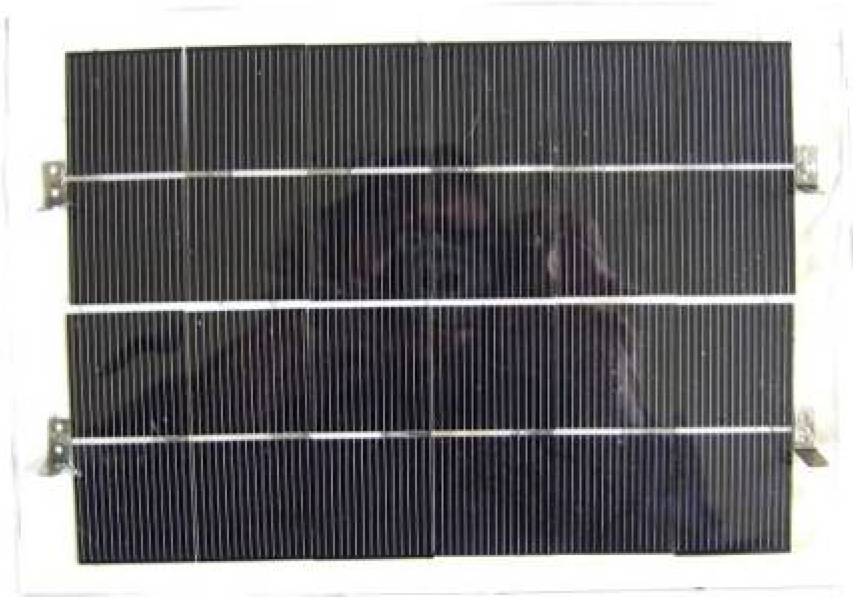
I make this suggestion only as a starting point that will allow students to assemble a drive system that will function reasonably well in Sun conditions from 20% up. The purpose is to get them started without the disappointment of a system that does not function. From initial success they can experiment and improve their boat.

The components and panel configuration suggested below are by no means the only ones that will function, they are however the ones I have tested and proven to function in combination. Neither is the combination of panel configuration and propeller tested here necessarily the best. Testing and experimentation is required by the students.

Solar Panel:

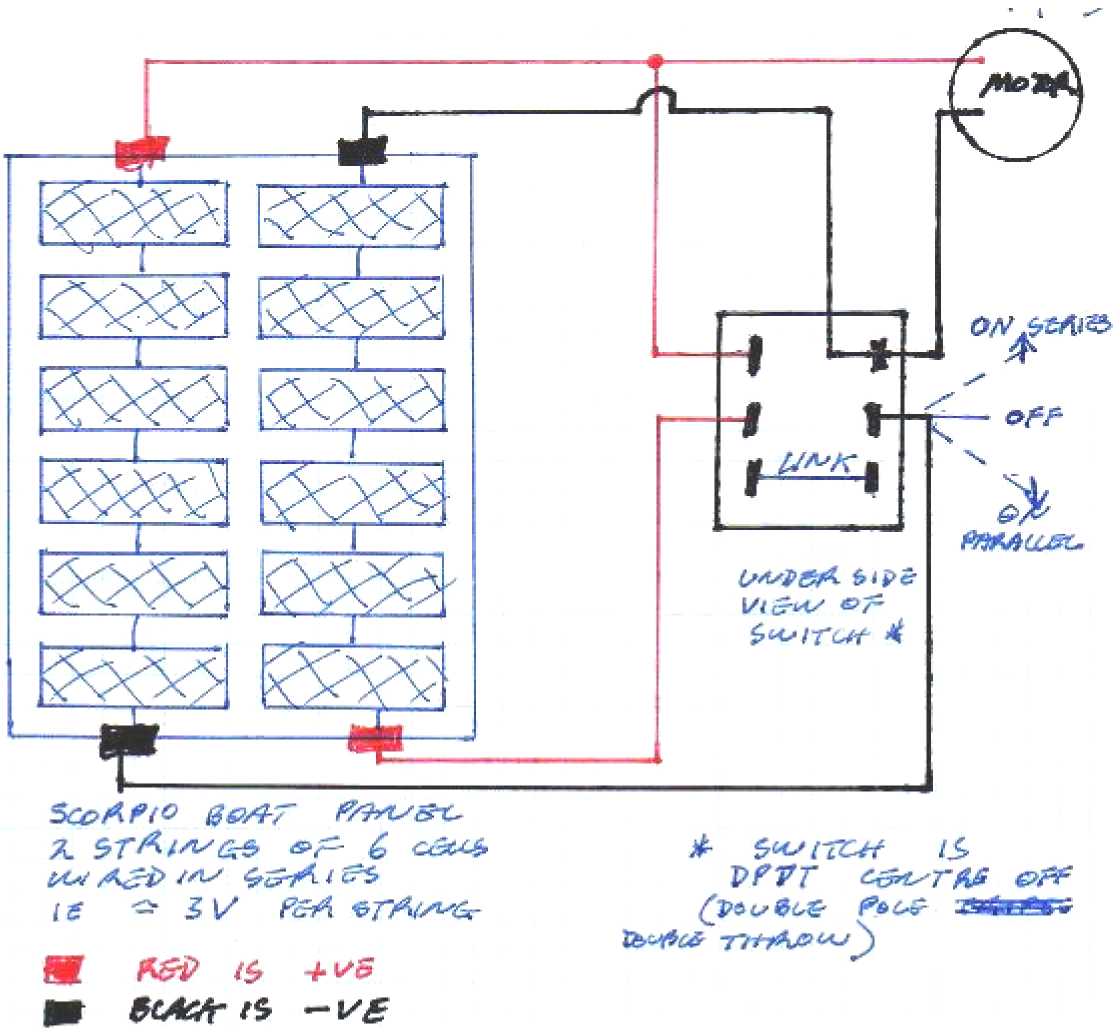
Use either **Scorpio Technology boat panel**. For simplicity connect the two strings of cells in parallel ie. connect the two positive terminals together and then to motor positive, and the two negative terminals together and then to motor negative. Experimenting with series connection of the 2 strings of cells can be done later.

(Take care this panel is built very light weight and is flimsy and easily damaged. Reinforce it if you cannot rely on students to handle it carefully see appendix 7 in Master Boat Workshops. The panels are not available at time of writing but supplies are ordered and expected be available soon)



Photograph of Scorpio boat panel 2008 production

If you wish the Scorpio panel can be wired in series or parallel selected with a switch. A double throw double pole centre off switch is used, it should be wired as shown below.

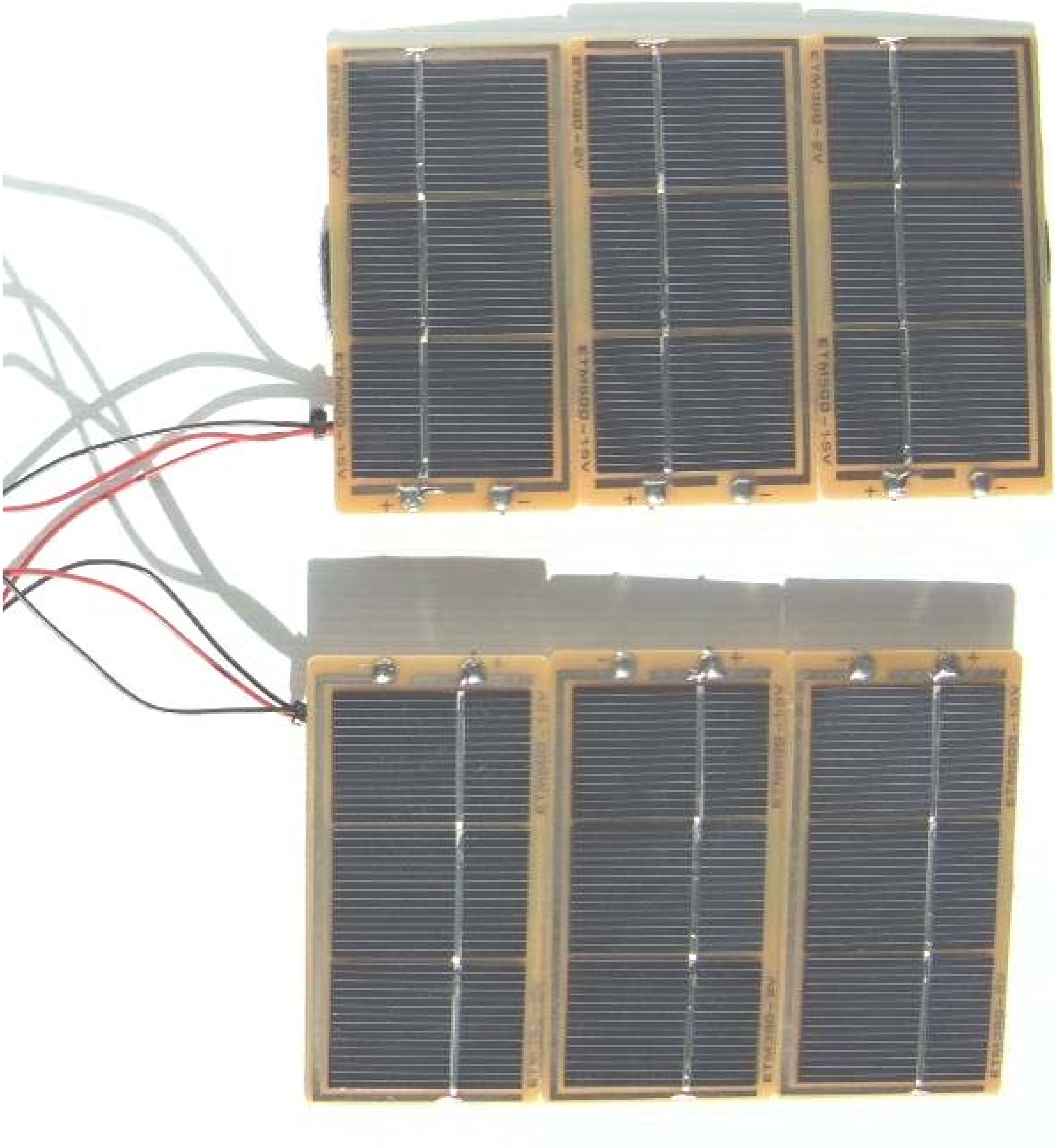


Or **6 Dick Smith cell segments 1.5 Volt 0.5 Amp cat no. O 2015**

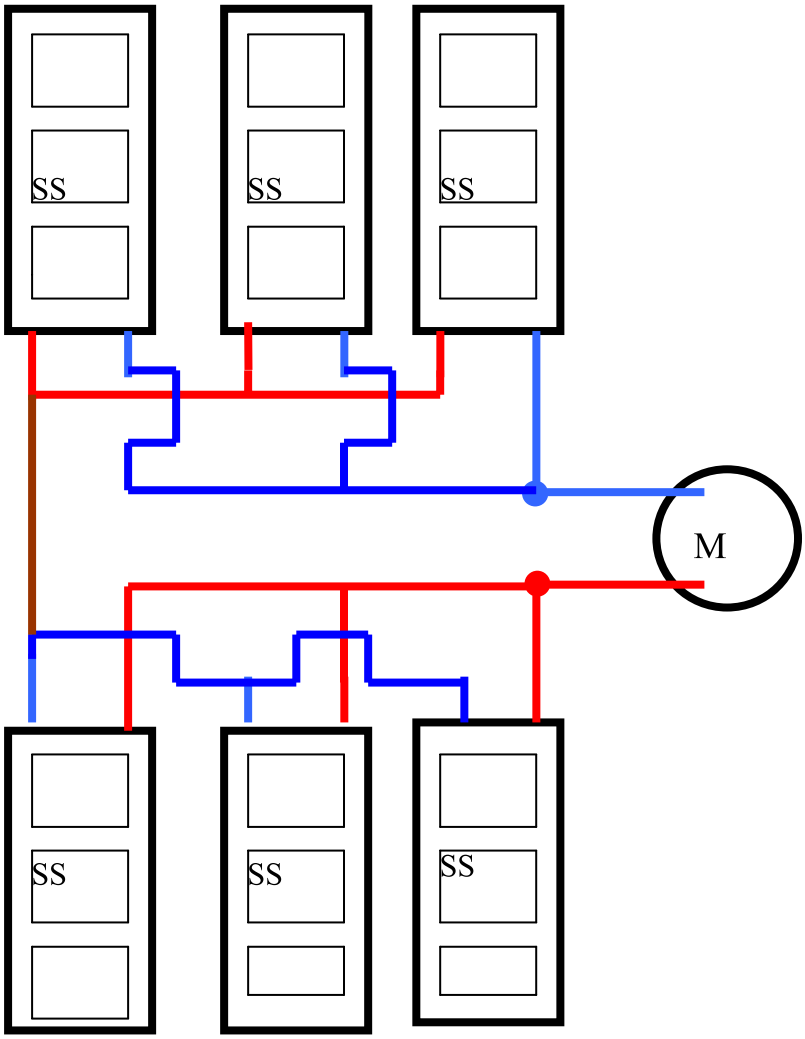
Note the current Dick Smith segments are larger in overall size than Those shown below but are electrically identical.

Engelec and CAM Art Craft & Technology have cells virtually Identical to those shown in the photograph.

They should be connected as follows – 2 groups each of 3 segments connected in parallel, (ie. positive to positive and negative to negative) these 2 groups are then connected in series (ie. negative of of one group connected to the positive of the other group) Again experimenting with other segment connections can be done later.



Photograph of 6 Dick Smith segments as used on test boat



Circuit diagram for connecting the 6 Dick Smith segments
Blue is negative
Red is positive
Brown is an interconnecting wire

<u>Motor:</u> 2009 model Scorpio Technology Solar Motor this exact motor no longer available

<u>Propeller:</u>

Either **Scorpio Technology 30 mm diameter 2 or 3 Blade propeller or other similar units from any supplier.**

Radio Active 30 mm diameter 3 Blade propeller
This is available from many hobby shops and CAM Art Craft & Technology. They are available as a kit complete with stern tube which may be of great help to you.

Larger photograph of Radio Active 30 mm diameter Propeller

Coupling:

This depends on your design, but if the motor can be out of alignment be sure to use a soft flexible coupling to minimise losses. Silicon rubber model aircraft fuel tube is suitable.

STATIC THRUST TESTS:
Static thrust tests were performed using the Solar Panels described above and a 30 mm diameter 3 blade Radio Active propeller coupled to a Scorpio motor Note this motor was a 2009 model. The solar panels were illuminated with a light box for this test. (Refer to notes in Master Workshop Document for discussion on change of thrust with moving boat)

Test 1: Dick Smith panel 2 groups of 3 segments in parallel , then these 2 groups connected in series. Maximum output at 100% Sun 3 Volts and 1.480 Amps.

% Sun	Thrust in gm
100	72
80	72
60	62
40	40
20	16
10	No Run

Test 2: Scorpio panel connected in parallel. Maximum output at 100% Sun 2.8 Volts and 2.04 Amps. Note: current (2012) Scorpio panel has output of 3.5 volts and 1.6 amps

% Sun	Thrust in gm
100	100
80	93
60	84
40	69
20	34
10	11

ADDITIONAL DATA FOR ADVANCED DIVISION :

I assume that students in this division will probably want to build a boat with better performance presumably with a high class motor. To this end I have included the following test data on a Faulhaber 2232 6 Volt motor. (Cost approx. $80 to $ 160 depending on where purchased)

Note: Additional propellers were tested as this motor delivers significantly more torque and requires additional load to make use of this additional torque. Results are recorded below.
The data presented here is a starting point only refer to Appendix 8 for up to date data on tests of motors, propellers, gear reduction systems and electronics.

ADDITIONAL TESTING WITH FAULHABER MOTOR:
Additional testing was then performed in the same manner as above but using a Faulhaber 2232 6 Volt motor instead of the Scorpio motor.
This type of motor is suitable for use in the Advanced and Senior divisions and has been used by many competitors at the national event.

Propeller details:

- **R/A 3/30 is Radio Active 3 Blade 30 mm Diameter propeller**
- **R/A 3/40 is Radio Active 3 Blade 30 mm Diameter propeller**
- **S 2/30 is Scorpio 2 Blade 30 mm Diameter propeller**
- **R/A 2/35X is Radio Active 2 Blade 35 mm Diameter X Series propeller**
- **R/A 2/35 is Radio Active 2 Blade 35 mm Diameter Std. Series propeller**

Test 1: Scorpio Solar Panel

% SUN	R/A 3/30		R/A 3/40		S 2/30		R/A 2/35		R/A 2/35X	
	S	//	S	//	S	//	S	//	S	//
100	135	40	140**	60	136	78	140	106	NOT TESTED	
80	120	40	130 **	63	108	75	131	88		
60	100	40	74	58	81	74	100	88		
40	65	34	48	52	54	65	68	80		
20	34	28	17	39	24	49	30	60		
10	15	25	7	26	9	24	12	33		

**** For these tests the torque reaction was so severe that an accurate reading was not possible due to the twisting of the balance.**
Thrust obtained in gm. is shown in the table. The panel was configured with all cells in series denoted as Series in the table or 2 strings of cells parallelled denoted as // in the table.

Test 2: Dick Smith Solar Panel

% SUN	R/A 3/30		R/A 3/40		S 2/30		R/A 2/35 Std.	
	S	//	S	//	S	//	S	//
100	90	30	125	62	114	63	81	150
80	88	30	100	58	92	63	64	127
60	78	29	71	51	73	63	39	94
40	60	27	51	52	5	69	23	64
20	30	25	22	25	2	38	9	31
10							0	14

Thrust obtained in gm. is shown in the table. The panel was configured with all 6 segments in series denoted as series, or 2 strings of 3 segments connected in series parallelled together denoted as // in the table.

APPENDIX 8: MOTOR AND PROPELLER TESTS INCLUDING DIRECT DRIVE AND GEAR REDUCTION.

The data presented in this appendix is complex in nature and predominantly aimed at the Advanced division. The data included at the end of this section detailing thrust obtained from various motors in direct drive configuration will be of use in selection suitable motors and propellers for the Junior division.

BACKGROUND:

In support of lowering the allowed cost of motors in the Junior division to $ 5.00 I conducted extensive tests on sample motors using different propellers.
From these tests I concluded that there were many suitable low cost motors available from many different suppliers and a reduction in motor cost would not detract from the competition. In fact two motors from CAM Art Craft & Technology here in Melbourne exhibited excellent performance. Using a Scorpio boat panel with nominal output of 7.0 volts and 0.84 amps at full Sun as the power source for all testing, these motors from CAM designated CAM28 and 28MOT09 significantly outperformed all other low cost motors tested, with the 28MOT09 appearing slightly superior to the CAM28 and giving thrust per amp values in Sun ranges above 15% Sun similar to the very expensive Faulhaber 2232 6 volt motor which is not permitted in the junior competition because of its high price. See attachment A for CAM motor performance graphs.

The Faulhaber 2232 6 volt motor is used as a yardstick to compare other motors to as this motor is in almost universal use in the advanced competition so is a good reference known to most competitors.
During testing of the Faulhaber motor it became obvious that all the available power from the motor could not be transmitted to the propeller through the silicone rubber tube normally used by competitors in direct drive configuration. At high Sun levels, particularly when using an electronics unit the coupling would fail, by either slipping on the shaft or being twisted into a pretzel shape. This failure has been observed at the competition and is not a new problem.

In trying to overcome this problem so I could get comprehensive results I investigated many coupling options but could not find a suitable solution that reliably transmitted the power without unacceptably high losses.
Eventually it became obvious that a gear drive presented the best solution. For testing a gear drive system based on R & I components was constructed. This system also offered significant improvement in motor to shaft alignment over that normally found in direct drive boats. In fact this system is excellent it offers perfect and permanent alignment while forming a “stand alone” drive system with motor, shaft gears and propeller all in one robust unit.
In addition a gear drive allows easy and quick changing the shaft speed which widens the choice of propellers and can indeed lead to increased motor and propeller efficiency. Significant improvements in static thrust were measured during testing of a reduction gear drive compared to direct drive, in the order of 250% is detailed in the latter part of this report.

Boat Drive System Basics:

Matching of motor solar panel and propeller are critical to obtaining the maximum propulsive force.

Firstly consider how to obtain the maximum propulsive force possible, the following discussions will help your understanding.

PROPELLER PITCH ELECTRONICS OR GEAR REDUCTION:

The bottom line of obtaining best possible boat performance after building a good hull is converting all the available solar panel power to propulsive force. Easy you think just drive a propeller with an electric motor. Well yes, simplistically that is what is required. However solar panel, motor and propeller characteristics all interact in a quite complex way. For maximum energy transfer it is critical that the correct combination is selected for the prevailing Sun level. If an electronics unit is not in use even a small variation in Sun level requires a change in set up if maximum energy transfer is to be maintained. If an electronics unit is in use a large change in Sun level (say more than 40%) most probably requires either a change in drive ratio between the motor and propeller or a change of propeller pitch if maximum energy transfer is to be maintained. Obviously it goes without saying that the motor chosen should have the highest efficiency and lowest no load running current possible.

In an attempt to understand what is happening consider the simplified description of the component characteristics given below. In particular remember they must all be at their best operating position and energy matched to each other for the Sun level prevailing if maximum energy transfer is to be achieved.

- Solar Panel: Solar panels produce their maximum power at a nearly constant voltage which drops only slightly as light levels drop from 100% to about 18% then falls rather faster as light levels drop to zero. The current produced by the panel varies directly with light intensity. This has important implications for our electric motor see below.
- Motor: For the small permanent magnet brushed DC electric motors typically used on boats, supply voltage controls the motor RPM with RPM being directly linked to voltage, the exact relationship between voltage and RPM is determined by motor construction and for a Faulhaber 2232 6 Volt motor is just over 1100 RPM per volt. So at 5 volts the motor would have a free running speed of 5500 RPM. Torque on the other hand is controlled by and varies directly with current. Increasing current increases torque.
- Propellers: Firstly some basics. Diameter, this is obvious but pitch may not be familiar to many new competitors. Pitch is the distance a propeller would advance in one revolution assuming no slip, it may be convenient to think of the propeller as a screw thread advancing into a nut as it is rotated. Because it is operating in water which is not a solid substance slip will occur ie. the propeller will not advance a full pitch worth of distance but some distance less each

revolution. This difference is the slip. Typically for a medium to lightly loaded propeller this slip will be in the order of 10% to 20%. The power absorbed by a propeller varies significantly with RPM, one text suggests it varies with RPM raised to the power 2.8 ie. nearly cubed. Hence only a slight change in Propeller RPM results in a large change in power required. There are even more variations in propeller design and construction to complicate the issue ie. pitch diameter ratio, number of blades, blade area, rake and whether to use a surface piercing or submerged propeller.

This covers the basics of each major component in our drive system, now the tricky bit, how they all behave and interact in combination.

Consider a boat without an electronics unit running at constant speed in constant Sun and the system in balance

The solar panel is supplying power to the motor at effectively constant voltage, the motor is running at an RPM dictated by this voltage. The propeller is being supplied with all the power it requires at this operating point and the system is in balance and stable.

Now consider what happens if the light level increases. More current is available from the panel but its voltage has not changed, so the motor RPM will not change and there is no requirement from the propeller for more power. Effectively nothing changes more power is available from the panel but we cannot take it into the system as it is. To get at this extra available power we need to either increase the motor RPM not possible as do not have any extra voltage, or increase the propellers demand for power which means we either speed the propeller up or increase its pitch. **So to obtain and use the extra power available we need to do something.** Either increase motor RPM or propeller pitch.

Now consider what happens if the light level drops below what it is in the balanced condition described above. Less current is available so the motor can no longer provide the torque needed to drive the propeller, the motor is slowed down until the power required by the propeller is reduced to the power available from the panel (remember power = RPM x Torque) the problem is that as the motor is slowed down its terminal resistance drops meaning it is trying to take more current from the panel which cannot supply any more current. The end result is a lowering of the panel voltage with a consequent significant reduction in available electrical energy. In simple terms a slight overload results in a significant drop in panel power and boat performance. **Again to maintain maximum energy transfer we must do something.** Reduce the load on the propeller by either slowing it down by use of a reduction ratio or by configuring the panel in parallel thus reducing the voltage and hence the motor RPM, fitting a lower pitch propeller or even changing the motor for one with a lower operating RPM is another option.

The use of an electronics unit maintains the solar panel at its maximum power voltage (if you set it correctly) so this part of the problem is taken care of but at a high motor load for the sun level prevailing, which occurs if the propeller has too much pitch, the motor voltage will be low and so will its speed which means the motor is operating

well away from its most efficient point. There are also the losses in the electronics unit to consider. When working hard the electronics is probably only about 80% efficient further adding to the losses.
Even when using an electronics unit better performance will be obtained if the motor voltage is closer to the panel maximum power voltage, which is not working the electronics as hard and therefore it has reduced losses as well as the motor spinning faster and operating closer to its most efficient point.
Really what we are saying is that for best performance even with an electronics unit a propeller with pitch near to the optimum for the sun level prevailing is required if maximum performance is to be obtained.

In fact the best performance will be obtained without electronics as long as: the propeller pitch is chosen to suit the boat and sun level prevailing at that time. The propeller must be changed for one with a suitable pitch if the sun level changes, we can probably get away with a propeller change about every 20% sun variation without the losses becoming too great.

As a range of small propellers each with a different pitch is hard to source, an option is to go for a high pitch propeller and drive it with a reduction gear ratio. The gear ratio can then be changed to vary the propeller load as sun level changes, a gear drive allows for many changes in drive ratio to be easily made with the consequence that it is possible to be near the matched point of motor propeller and panel at all sun levels. This will result in better performance than relying on just one ratio and an electronics unit. The biggest problem is gear reduction units are complex and probably beyond the scope of young students.

The graph below shows this performance variation clearly. These tests were performed on the Prop shop prop driven by a Faulhaber 2232 6 volt motor with various reduction ratios. The gear system used is standard R & I gears and motor mount slightly modified to allow the motor to mount closer to the prop shaft with the motor mount plate attached to the opposite side of the mounting flange. See photograph earlier. Static thrust obtained was measured at motor voltage of 7 volts which is the maximum power voltage of a Scorpio boat panel.

NOTE: Static thrust has been tested and reported here, this skews the results somewhat, as it tends to stall the motor down to lower RPM and uses more power than a boat that is running free. The exact difference is impossible to predict but as a rule of thumb you can expect the load to be reduce by about 30% on a free running boat. This effectively means that in these test results when we see the panel is fully loaded at 7 volts it will in fact somewhat under loaded when driving a free running boat. Only by on water testing can we ascertain the exact gear reduction required. The graph however does give a starting point for testing.

Probably the best way to determine panel loading when testing a boat free running is to measure the panel voltage. Solar cells produce maximum power at about 0.5 volts per cell so by simply multiplying the number of cells in series by 0.5 volts we have the maximum power voltage of that panel. As an example consider the Scorpio boat panel with 14 cells in series the maximum power voltage is 7.0 volts.
Do take care that whatever method you use to measure voltage does not slow the boat down and increase propeller loading thus causing inaccuracy in the results.

Propeller selection by calculation:
Unfortunately this is really difficult as motor performance data is generally not available for the hobby motors. Neither is data on the propeller pitch for the average model boat propeller. Data for both these is required to make a reasonably accurate prediction of what is required.
To illustrate consider the Faulhaber 2232 6 volt motor, as this is an industrial motor full motor performance specifications are available.

We know that the best boats can run the length of the pool in 3.5 seconds that is a distance of about 9500 mm. So what propeller pitch is required to achieve this?

For this exercise assume the motor is using all the panel power available at full Sun from a Scorpio boat panel that is 0.8 amps at 7.0 Volts.

The speed constant for this motor is 1190 RPM per volt so at 7 volts it will spin at

7 x 1190 =8300 RPM unloaded

The torque constant is 8.03 mNm per amp so at the panel current of 0.8 amp

0.8 x 8.03 = 6.4 mNm torque

The slope of the torque RPM curve is 120 RPM per mNm so to develop this torque the motor must be loaded sufficiently to slow it by

120 x 6.4 = 768 RPM

So the actual loaded running speed of the motor is

8300 – 768 = 7532 RPM

Consequently in the 3.5 seconds taken to traverse the pool the motor shaft does 439 revolutions. Which is 125 revolutions per second.
As the boat travels the 9500 mm pool length while the motor does 439 revolutions the propeller must advance the boat 9500 mm divided by 439 = 21.6 mm per revolution, this is the effective pitch of the propeller the actual pitch is this number plus the slip which is probably around 20% consequently allowing for slip the actual propeller pitch needs to be in the order of 21.6 x 1.2 = 25.9 mm (or just over 1 inch)

The 30 mm diameter 3 blade propellers from Radio Active and Live Steam both are near to this pitch by my rough measurements and would be good candidates for initial testing.

The above calculations are for direct drive if a reduction ratio is to be used you must adjust the propeller RPM accordingly.

TEST METHOD:

Static thrust measurements have been used in all the tests as I have no facilities for free running tests on boats.
NOTE: Static thrust skews the results somewhat, as it tends to stall the motor down to lower RPM and uses more power than a boat that is running free. The exact difference is impossible to predict but as a rule of thumb you can expect the load to be reduce by about 30% on a free running boat. Consequently we cannot take the propeller that may appear to be the best in these tests and use it on a boat without first testing it on a

free running boat to verify it is in fact the best choice. When conducting free running tests an easy way to determine the panel loading is to measure panel voltage with the boat running free.

Below are photographs showing the test set up. The motor and propeller under test were suspended vertically on a balance with the propeller submerged in a water container. The thrust produced is read from the balance.
Power is supplied by a voltage and current regulated power supply. Note the graphs showing the results have the voltage and current limits of various solar panels in different wiring configurations shown. This allows us to make a reasonable judgement within the accuracy of static thrust tests as to the best panel and indeed wiring configuration for that motor and panel combination at different Sun levels.

All results are shown graphically which allows quick evaluation and comparison of different test results. **Do take the time to properly examine and consider the graphs they contain a large amount of very useful data.**

<u>HOW TO READ THE GRAPHS:</u>
Firstly look at graph 1 showing results for the Faulhaber 2232 6 volt motor in direct drive configuration. The graph on the right shows static propeller thrust against amps. It can be seen that there is some significant difference in thrust provided per amp of motor current from propeller to propeller.
Consequently we should choose a propeller that has the best thrust per amp as long as it allows full panel current to go to the motor at a bit below the maximum panel voltage.

Now look at the graph on the left: the vertical and horizontal dashed lines of different colour represent the voltage and current available from solar panels in the nominated series / parallel combination, you can never operate outside the boundaries shown for the panel under consideration. The blue dashed lines at 7 volts and 0.8 amps represent the limits for the Scorpio boat panel connected in series. This is the panel used in all the tests in this document.
Because static thrust overloads the motor, as a starting point for free running tests choose a propeller that uses all the current at full Sun at between 2/3 and 3/4 of the maximum 7 volts, this should allow for extra motor RPM as the load is reduced when free running.

Remember for the Faulhaber motor voltage is directly proportional to motor RPM and torque is directly proportional to current, the graph can therefore be considered as a torque RPM graph. You can also easily calculate the power being used from the panel for any propeller by simply multiplying the voltage and current corresponding to the point of interest on the graph. Voltage multiplied by Current = Power in a direct current circuit. (Watts)

The current is also a gauge to Sun level as current available from the panel varies directly with Sun intensity.

DETAILS OF TESTING & RESULTS

Panel characteristics used in the graphs for Scorpio panel is based on the 2011 production 6 Watt Scorpio boat panel that weighs in at about 50g

Panel connected in series and at full Sun

VMP 7.1 volts

IMP 0.84 amps

Panel connected in parallel at full Sun

VMP 3.5 volts

IMP 1.68 amps

Panel characteristics for the 3 cell CAM segments which are electrically equivalent to the 3 cell Dick Smith segments, are

For 1 segment in full Sun

VMP 1.5 volts

IMP 0.5 amps

Six of these 3 cell segments equal the maximum area of cells allowed under the regulations. The data on the graphs show segments connected as follows:

All 6 in series giving 9.0 volts at 0.5 amps

Two groups of 3 segments in series then the 2 groups in parallel

giving 4.5 volts at 1.0 amps

All 6 in parallel giving 1.5 volts at 3.0 amps

Not shown: Three groups of 2 segments in series then the 3 groups in parallel

giving 3.0 volts at 1.5 amps

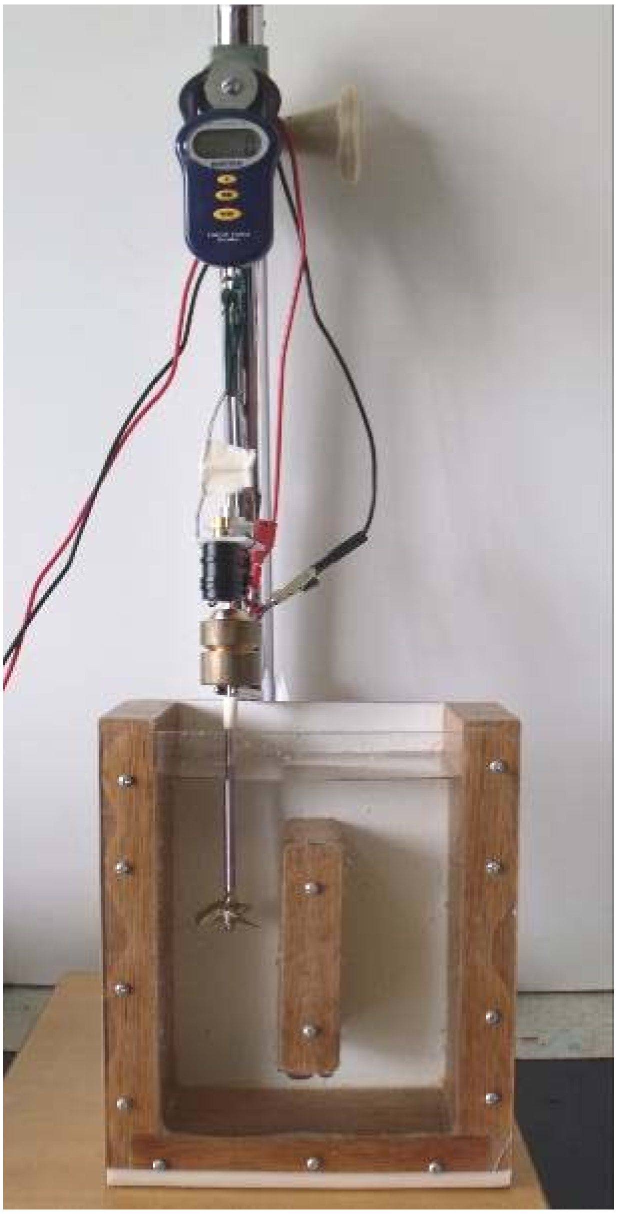
PROPELLERS USED (Some are shown in the photographs below)

Propeller details are given in the table below arranged top row left to right, centre right then bottom row.

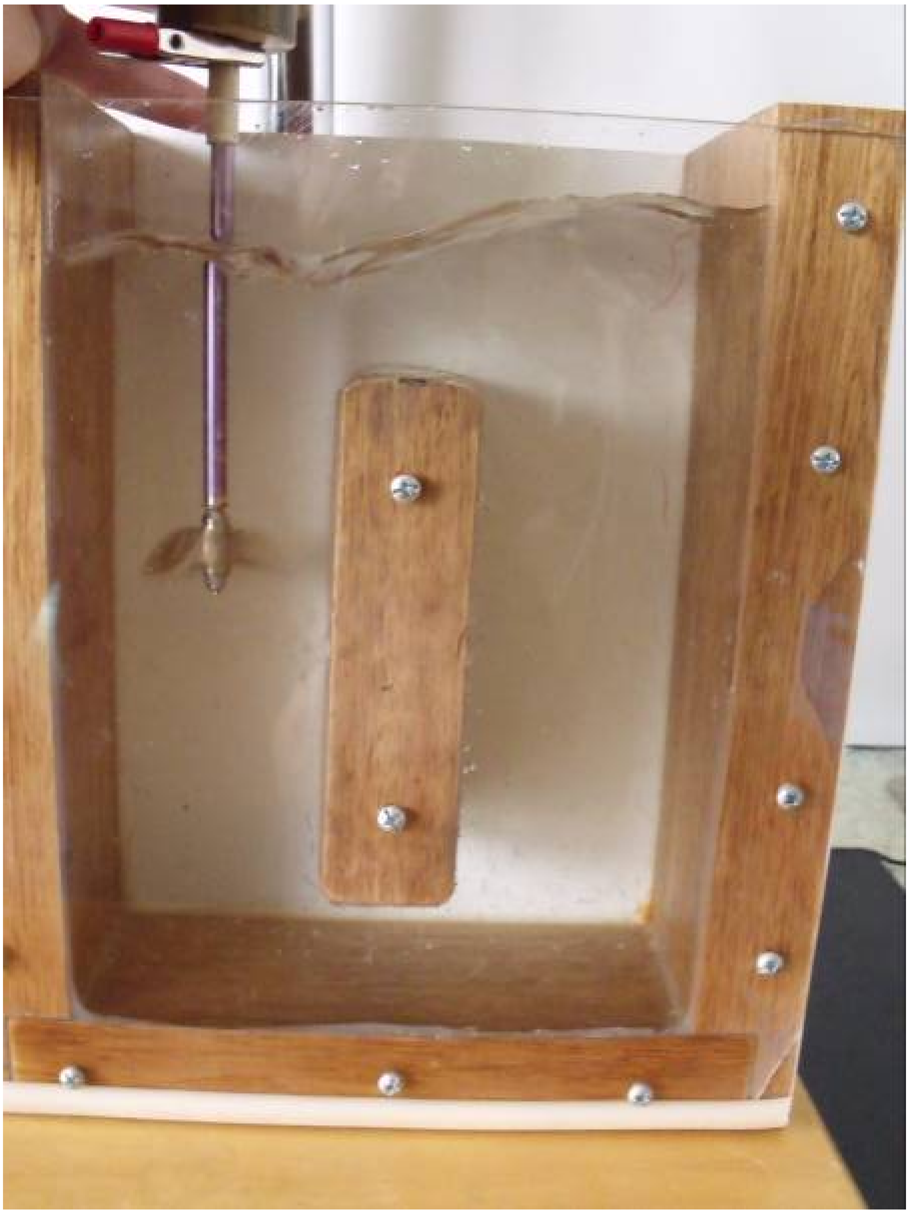
Manufacturer Test code	Part number	No. of blades/dia	Material	Shaft fixing
Radio Active ! R/A 30 dia.	MA 3045/A	3/30mm	plastic	M2
Radio Active R/A 40 dia.	MA 3045M2	3/40mm	plastic	M2
Radio Active R/A 35 dia. 2 blade	MA 3030	2/35mm	plastic	M4
Live Steam Live steam 30 dia.	30 RH	3/30mm	brass	M4
Prop Shop prop shop	4014/3	3/42mm	bronze	dog drive
Graupner Gr 20	2307.20	3/20mm	plastic	M2
Graupner Gr 25	2307.25	3/25mm	plastic	M2
Aquacraft AQ28	AQUB7755	2/28mm	plastic	dog drive
Scorpio !!! Scorpio 2bl	2blade-28mm	2/28mm	plastic	2.5mm push

! Scorpio have a nominal equivalent push fit to 2.5mm shaft.
!!! CAM have an identical prop

TEST SET UP:

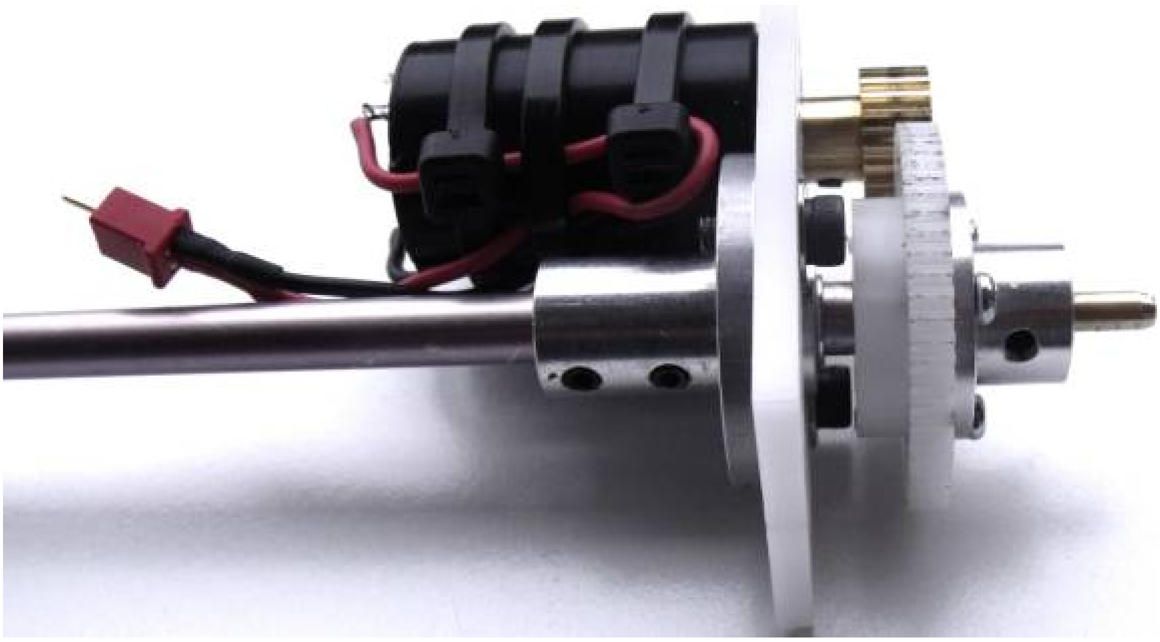


Motor and propeller in place in water "jar"



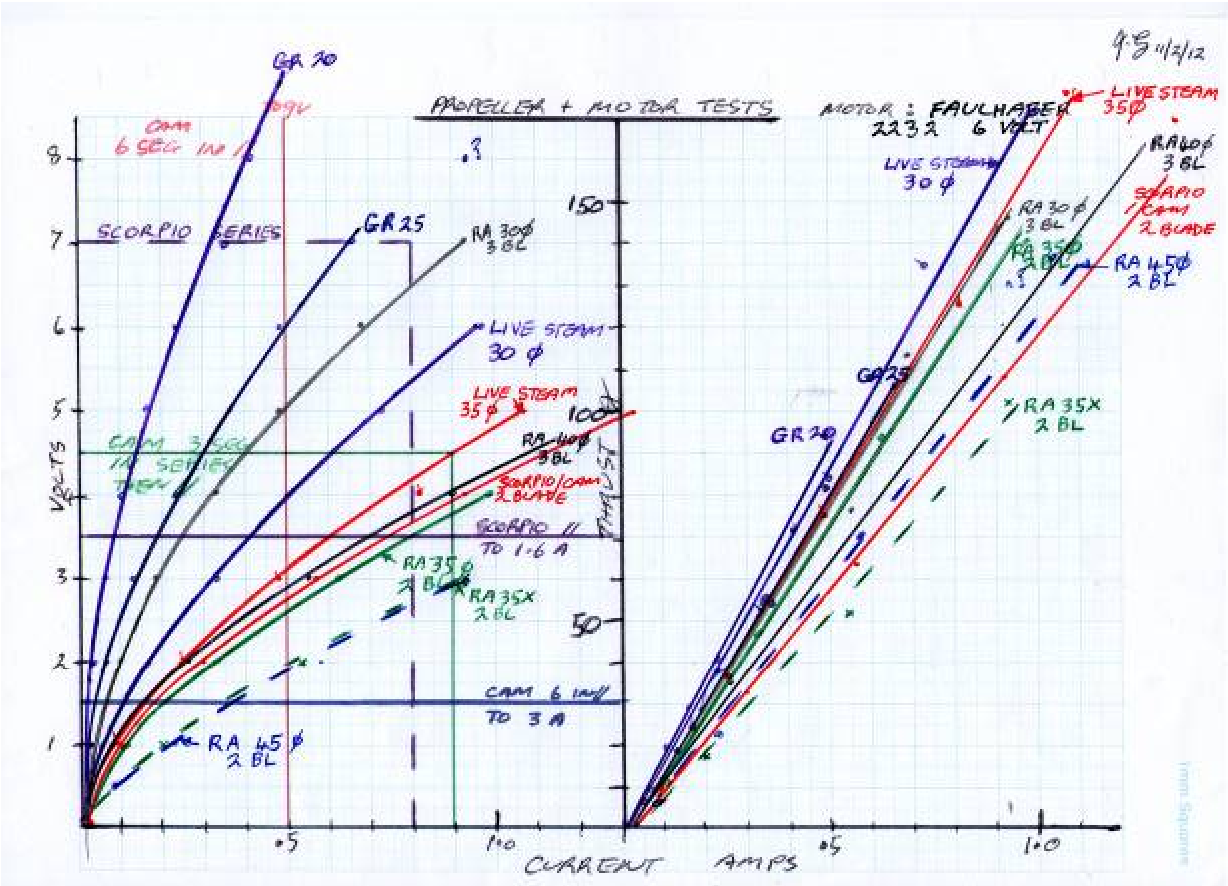
Close up of test, note the test jar allows for water flow around the centre baffle which gives more stable readings when compared to a single chamber test jar.

The photographs below depict the gear reduction set up based on R & I car motor mount system that was used for the gear reduction tests. NOTE: Motor current no load 0.028 amps & when driving prop in air 0.061 amps at 6 volts. Weight of motor and gear reduction assembly 91 g, motor alone 62 g. R&I Instrument Gear Co. are manufacturing the components required for this unit. They may vary slightly from the components shown here.



TEST RESULTS:

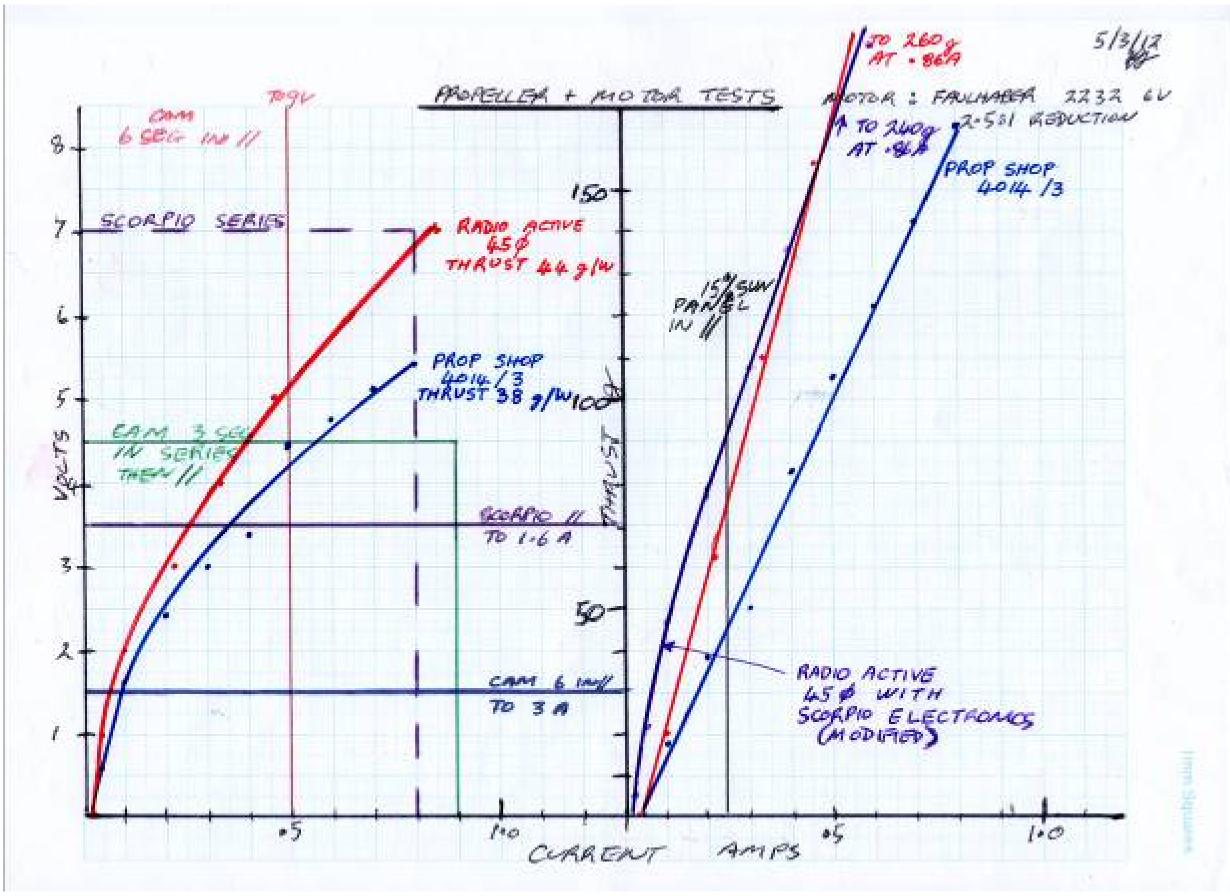
The graphs below depict the results obtained from tests using a Faulhaber 2232 6 volt motor using direct drive via a silicone rubber tube.



Graph 1 Faulhaber 2232 6 volt direct drive with propellers various.

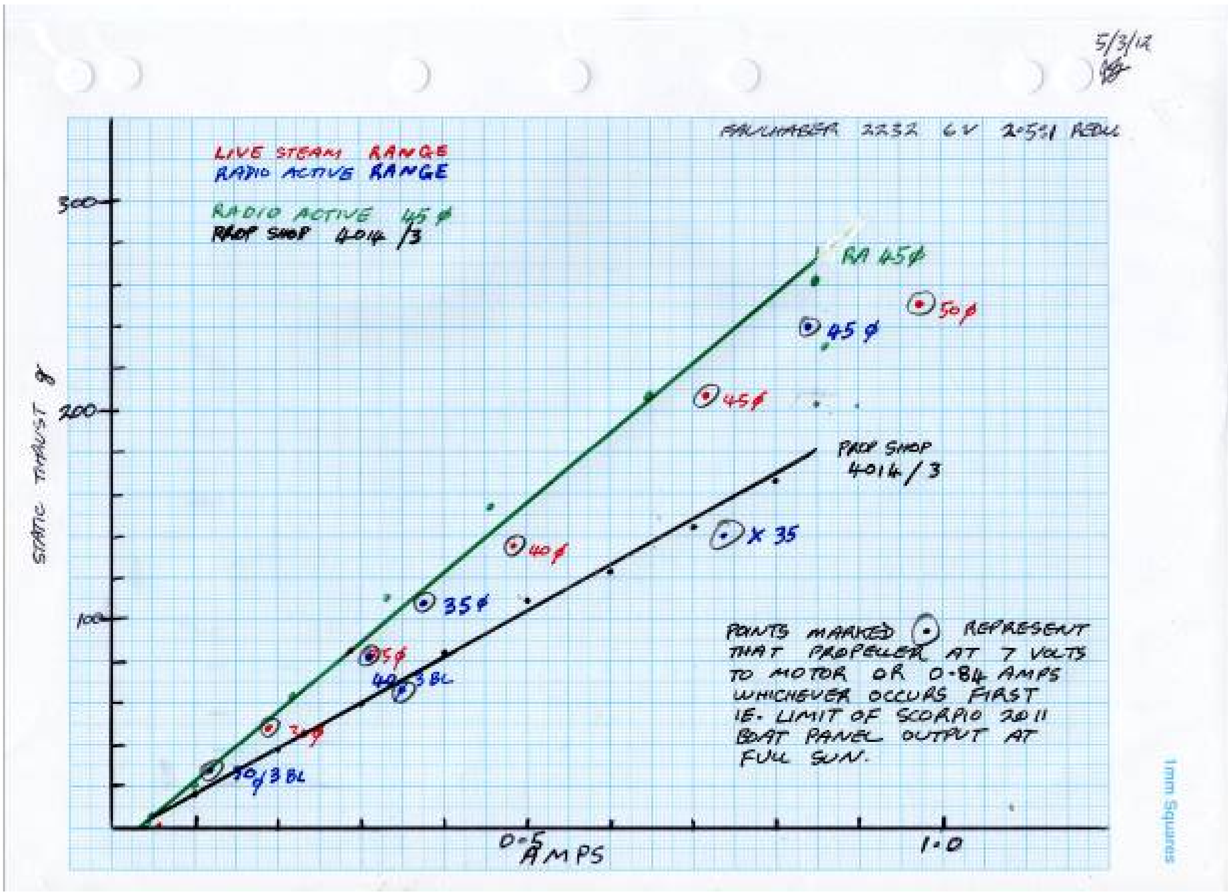
The graphs below show Faulhaber 2232 at 2.5:1 reduction driving the Prop shop propeller and the Radio Active 45 mm diameter 2 blade propeller.

Note: At 0.5 amp which is about 60% Sun the Radio Active propeller produces over twice the static thrust at 2.5:1 reduction than it does direct drive. And at 0.1 amp which is about 12% Sun the Radio Active propeller still produces about twice the thrust when the motor is driven direct from the solar panel but if an electronics unit is used the thrust is about 4 times higher.



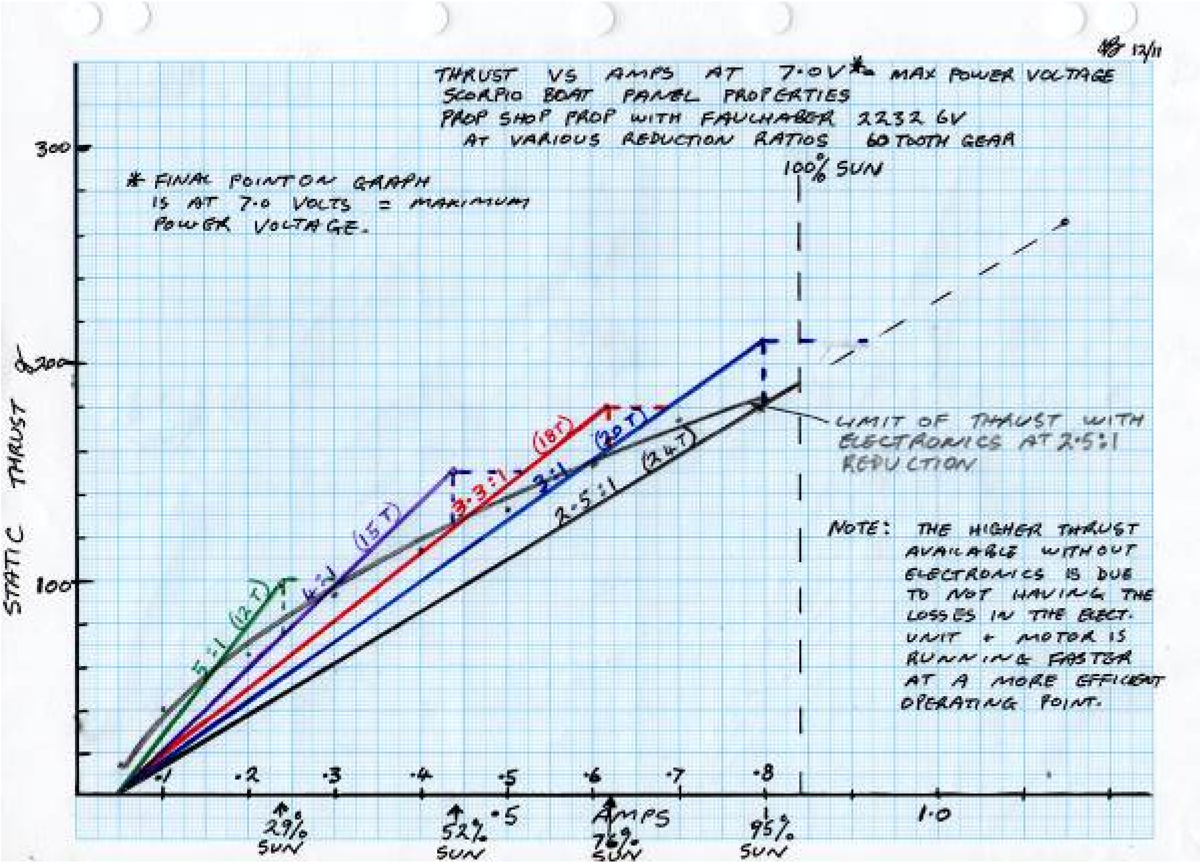
Faulhaber 2232 6 volt with 2.5:1 reduction ratio.

Note the significant thrust increase for the 45 mm diameter 2 blade propeller when compared to the thrust it delivered in direct drive configuration shown as curve RA 45 dia. On previous direct drive graph.



Faulhaber 2232 6 volt motor at 2.5:1 reduction propellers various.

Note: These tests were intended only to show which propellers were good candidates for further testing so only the thrust obtained at the maximum output point of the Scorpio panel was plotted for each propeller. Maximum output point is determined when either panel maximum volts or amps are reached.



Faulhaber 2232 6 volt motor at various gear ratios and with electronics at 2.5:1 reduction ratio.

The base data for the graph above is in the table below.

Panel Voltage	Motor Current A	Thrust (static) g	Pinion teeth	Gear Ratio (60 T gear)
7.0	0.24	98	12	5:1
7.0	0.44	150	15	4:1
7.0	0.64	166	18	3.33:1
7.0	0.80	210	20	3:1
7.0	1.15	263	24	2.5:1

SUMMARY:

The results presented here were not intended to give answers but to give direction to student investigations of propeller and drive system choice. Water testing with a free running boat is critical as hull design actual solar panel, motor and propeller characteristics all play a part in controlling performance.

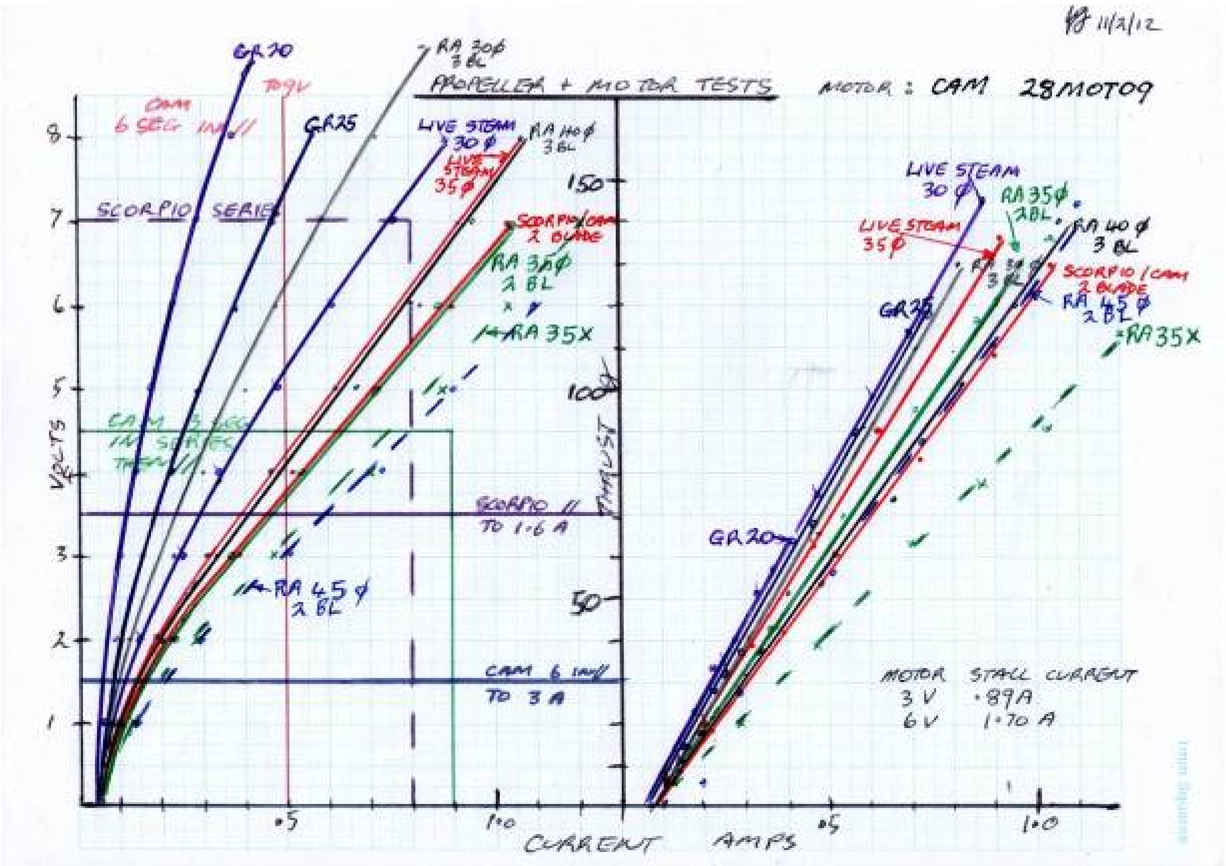
OTHER INVESTIGATIONS / ACTIONS:

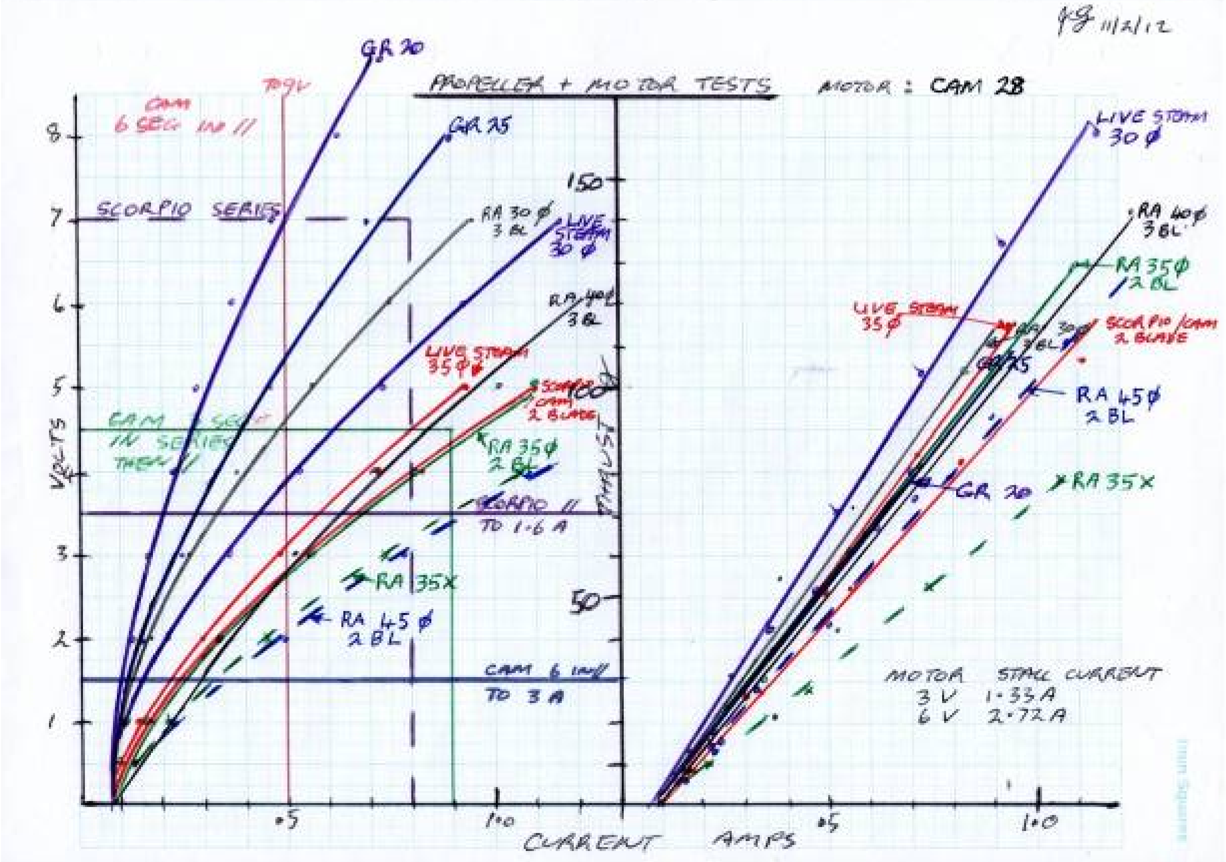
- **Surface piercing propellers**
- **Which propeller and gear ratio is best for your boat**
- **Should you use electronics or not**
- **Free running boat tests of possible options. This is absolutely critical as hull design and free running significantly changes loading on the propeller.**

ATTACHMENT A: CAM motor performance

These graphs are included for interest to demonstrate how good matching of motor, propeller and solar panel give a good outcome even for a low price motor. Tests were performed using direct drive and silicone rubber tube drive. Coupling tube failure is not an issue with these motors as they cannot provide the extreme torque available from the Faulhaber. I do fully expect that using these motors with a gear reduction system would increase performance similar to the Faulhaber results. This was not tested as only direct drive is permitted in the junior division and I did not expect any serious competitors to use these motors in the advanced division.

Only results for CAM motors are included here as I did not undertake extensive testing on other motors when the CAM motors outperformed them by typically 2:1.


11/2/12
PROPELLER + MOTOR TESTS
MOTOR : CAM 28MOT09
VOLTS
THRUST
CURRENT AMPS
CAM 6 SEG IN //
TO 9V
SCORPIO SERIES
CAM 5 SEG IN SERIES THEN //
SCORPIO // TO 1·6 A
CAM 6 IN // TO 3 A
GR20
GR25
RA 30 ϕ 3 BL
LIVE STEAM 30 ϕ
RA 40 ϕ 3 BL
LIVE STEAM 35 ϕ
SCORPIO / CAM 2 BLADE
RA 35 ϕ 2 BL
RA 35X
RA 45 ϕ 2 BL
MOTOR STALL CURRENT
3 V ·89A
6 V 1·70 A


11/2/12
PROPELLER + MOTOR TESTS
MOTOR : CAM 28
VOLTS
THRUST
CURRENT AMPS
CAM 6 SEG IN //
TO 9V
SCORPIO SERIES
CAM 5 SEG IN SERIES THEN //
SCORPIO // TO 1·6 A
CAM 6 IN // TO 3 A
GR 20
GR 25
RA 30 ϕ 3 BL
LIVE STEAM 30 ϕ
RA 40 ϕ 3 BL
LIVE STEAM 35 ϕ
SCORPIO / CAM 2 BLADE
RA 35 ϕ 2 BL
RA 35X
RA 45 ϕ 2 BL
MOTOR STALL CURRENT
3 V 1·33 A
6 V 2·72 A